Dental Histology and Embryology

B. ORBAN

Leonard D. Nathan

DENTAL HISTOLOGY AND EMBRYOLOGY

BY

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This little book is affectionately
dedicated to my teacher,
B. GOTTLIEB
Vienna,
as an expression of my gratitude
and heart-felt admiration of his
rare personality.

PREFACE

The normal histology of the teeth is described in many textbooks, yet there seems to be a need for a brief text which will be neither too short nor too detailed for the student and the practitioner. Many of the textbooks are introductions to pathology and presuppose a knowledge of dental histology on the part of the student. The larger texts give more material than is necessary for students and are of value only to investigators.

It is my desire in this book to give short descriptions of the various structures that comprise normal dental histology, illustrating everything mentioned with microphotographs. The descriptions are very short; in fact I have restricted myself solely to explanations of the photographs. The reader, for this reason, will be forced to concentrate on the study of the illustrations and the accompanying descriptions. It is hoped that this very liberal use of microphotographs will be of value to the student in acquiring a fundamental knowledge of the subject. To the busy practitioner it may recall the microscopic details of the gross structures with which he deals and serve as a commentary in the reading of dental literature. Because of the brevity of the text, scant reference has been made to the whole literature. A brief bibliography is given at the end of the book.

Many questions of dental morphology and histogenesis are being actively discussed at present, and the author's views presented here are the result of his investigations as well as those of others. It is hoped that teachers who hold opinions at variance with those of the author will use the book as a basis for discussion; to stimulate the student to independent thought, and to encourage others to attempt the solution of the many problems yet to be solved before a final statement of

facts can be made concerning the growth and structure of normal dental histology.

Since it has been the aim to make this book a brief text there are of necessity chapters in which seemingly important matters are not thoroughly discussed. Other significant topics are briefly treated deliberately because they constitute still unsettled and disputed questions. With the presentation of some of the disputed material from the author's point of view, he hopes to stimulate further investigation. He will appreciate any criticism, for it is only through criticism that real constructive work can develop.

The greater part of the illustrations used in this book are from the collection of the Histologic Laboratory of the Dental School of the University of Vienna, Director of the Laboratory, B. Gottlieb. Most of these illustrations have appeared already in articles published by members of the Laboratory. For three of the illustrations thanks are due to Dr. W. Meyer, Breslau. The illustrations used for the descriptions of tooth development were made from the material of the II Anatomical Institute, University of Vienna, Director, Prof. Dr. F. Hochstetter. The rest of the illustrations were prepared in the Laboratory of the Chicago College of Dental Surgery.

Chicago, June 15, 1928.

B. Orban.

INTRODUCTION

There are, as a rule, many defects associated with the presentation in monographic form of a morphologic branch of any science. Such a presentation frequently assumes a closed, to further discussion ipse dixit form, almost biblical in character, not allowing even the remotest doubt as to the validity of the matter under discussion. Such a form of presentation is motivated by the fact that such a monograph is produced to serve as a teaching manual and is to be used chiefly by beginners in the subject. For such beginners, according to this mode of reasoning, it is best to present the subject in a closed form without the introduction of any element of doubt. Such a concept appears to me entirely incorrect since thereby the door to scientific investigation is unwittingly closed to the young student. A new idea is conceived more easily by the youthful, unprejudiced mind than by the older, more experienced one hedged in by conventional inhibitions so that, as a consequence of its preconceptions, the latter may not see the forest because of its concentration on the trees. An additional reason for my opposition to this form of presentation arises from the tendency, whether consciously or unconsciously, to teach untruths to the young students, if we present a scientific subject in the closed form since in no science is such a status ever attained. In the final analysis this urge to present such a subject in an ipse dixit form arises from the evolution of the human mind along egoistic lines in such a fashion that it resents implications concerning its fallibility. The university is the last step before entrance into Life's activities. Here should be no place for dogmatic rigidity, but a place where everything is exposed to the clear light of day. We must have the courage to confess that there is much we do not know, that there

is much that is still in dispute, and even what we believe to be completely true is not sacrosanct and not to be doubted, since all science is human and nothing human is infallible.

There is a further error that is common to most presentations of morphologic subjects in that it is assumed that morphology is something quite stable and unchangeable. It is implied that morphology is in marked contrast to physiology in which change and mobility are striking features. One is accustomed to depict a given certain condition as normal in morphology. Even to do the latter is, as a rule, wrong, but a mistake of which all teachers have been frequently and unwittingly guilty. Even morphology does not deal with dead or fixed tissues. The morphology of every organism, of every organ changes constantly from day to day and year to year. One is accustomed to picture as normal that condition which is found in the body with full completion of the skeleton. But many organs undergo noteworthy alterations both before and after this time. Each period has its typical morphology and physiology, and it is neither exact nor helpful to portray the morphology of a given age of the organism as the normal. The gray hair of the person of seventy is quite as normal as the lanugo of the newborn child. Therefore it appears to me to be important to free morphologic subjects from the rigid concept of the normal and to lay the greatest stress on the changes in morphology that are associated with life processes. The cause of this form of error may arise from the fact that from the very beginning morphology has been taught from dead specimens, and in these dead specimens there is, naturally, no further opportunity for change. Momentary phases in the constantly changing cycle of orderly development have been unduly emphasized in the morphological sciences. Life is never ceasing motion and continuous change. Therefore, if we must separate morphology from vital processes and living organs—to study it and teach it, we must vitalize that study

and teaching by emphasizing in a noteworthy fashion this feature of ceaseless change instead of the unchanging normal. It is only in such a manner that we may hope to grasp these subjects.

A quite similar and common mistake consists in drawing a sharp line of separation between normal and pathological morphology. This may have had its origin in the increasing tendency to specialization in these morphologic groups. Indeed in the beginning normal and pathologic anatomy and physiology were united in one subject. The impression that the separation of these subjects makes in the minds of young students endures more or less permanently and is, I believe, fraught with serious consequences. Just as truly as the young organism does not become old overnight, neither does the healthy body become diseased in the same time, though there are some exceptions to the last clause, it is mainly true. It appears to me to be less important to teach how a diseased organ and a healthy organ appear than it is to show the gradual transition from a healthy structure to one that is diseased. The major emphasis must be placed on the first phase of the change from health to disease and the relationship of the one to the other diligently studied. If we would in reality seek to produce not merely therapeutists, but rather a new generation of practitioners who will be concerned chiefly with prophylaxis, a consummation which has been promised to humanity for years we must focus our attention on this early transition period from health to disease; and not, as often is the case, allow our activities to be limited by the borderline normal and diseased tissues and organs.

Finally it is the duty of such a presentation of a morphologic subject to maintain a close contact with practical matters by emphasizing important relationships that exist between form, structure, and clinical procedures. By doing this it is possible to supply a scientific foundation for practical methods, for none may endure except if so grounded.

Orban has striven in the following monograph designed for students and practitioners to realize the possibilities of these ideals. Because of the limit placed upon the size of this text it has not been possible to take in everything that may seem desirable. This must serve only as a first attempt to produce a text of this character in this field.

I ask a favorable reception for this book, which according to my belief, it richly deserves.

B. Gottlieb.

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CHAPTER I

THE ENAMEL

The enamel covers the "anatomical" crown of the tooth. A distinction is made between an "anatomical

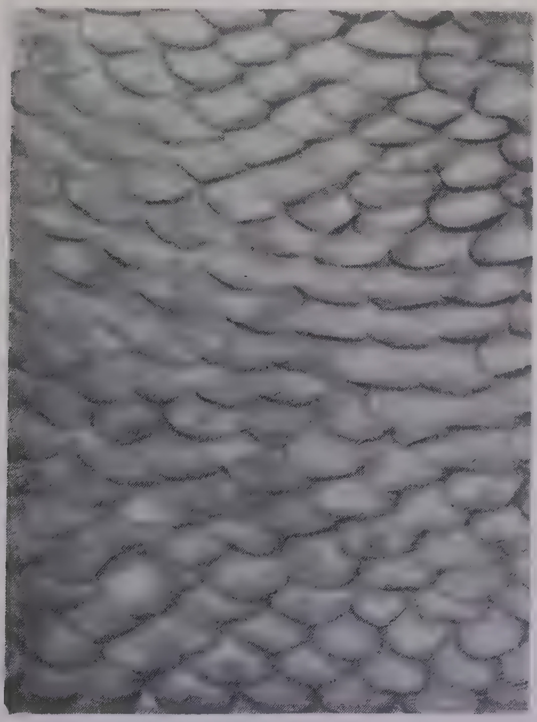


FIG. 1
Cross section of scale-like human enamel rods. The dark lines are the cementing substance, the areas between are rods.

crown" and a "clinical crown." The "anatomical" crown is the part of the tooth which is covered with enamel; the "clinical" crown is the part of the tooth which extends into the mouth and which may be smaller or larger than the "anatomical" crown. This

question will be discussed more fully in the chapter on the epithelial attachment.

Well developed enamel consists of about 97% inorganic and 3% organic substances. It is the hardest material in the body and has undergone a high degree of calcification. *It is composed of enamel rods between*

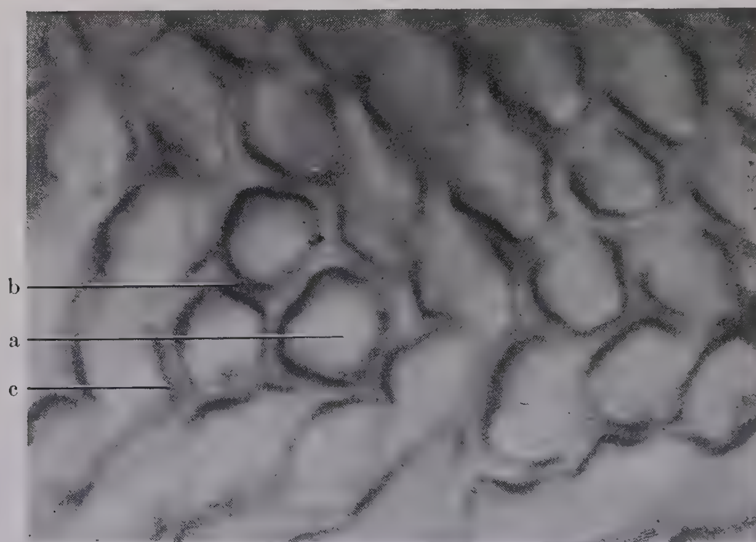


FIG. 2
Shape of enamel rods in dog's tooth.
a. body of rod. b. interprismatic substance.
c. organic sheath of rods.

which is found cementing or interprismatic substance.

Shape of rods

In cross section the shape of the rods is not the same in all species of animals. *In human enamel the scale-like shape is found* as shown in Fig. 1. The dark margin of the scales is the cementing substance which is an organic material that later may become calcified as the individual grows older. In the network of the cementing substance the calcified rods can be seen. Finally the enamel may be so well calcified that no

structure can be observed in it. The shape of the rods in dog's teeth as indicated in cross section is more regular, while between the rods is found a calcified interprismatic substance, as observed in Fig. 2. Here the calcified rods are surrounded by black lines which are the organic sheaths of the rods. Between the neighboring rods there is a substance which has the

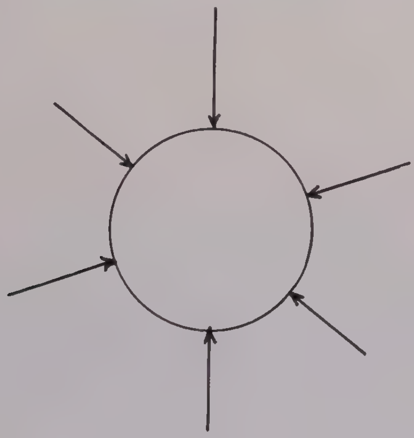


FIG. 3
Diagram showing course of calcification. Calcium salts penetrate the rods in the direction of the arrows.

same composition as the rods and is called interprismatic substance. In this photograph the three different structures can be noted—calcified rods, the organic sheath of the rods, and the calcified interprismatic substance. Calcified interprismatic substance can seldom be seen in human teeth. The rods in human enamel lie so closely together that mostly the interprismatic substance cannot form, only the sheath being present.

Manner of Calcification

The manner in which calcification takes place determines chiefly the shape of the rods. The calcification of each rod begins on the lateral surface and proceeds toward the center, as shown in the diagram. (Fig. 3)

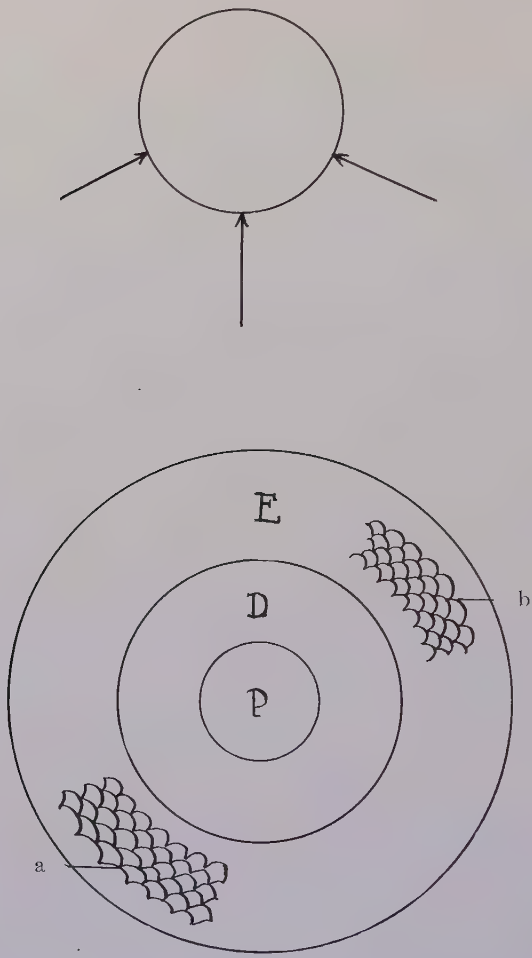


FIG. 4
Upper diagram—course of calcification in human enamel which proceeds from one side of the rod. Lower diagram—the calcification of each rod starts from the side nearest the dentin. The convex side of each rod faces the dentin. (a) The arrangement of rods indicated by b is never found.
E—enamel D—dentin P—pulp

In human enamel the calcification of the rods does not take place on the whole circumference of the rod at the same time, but *begins on one side*, that is, the side lying nearest to the dentin Fig. 4. Thus one side of each rod becomes harder than the other, and in the process of development, which is accompanied by pressure, the harder side presses into the softer side of the adjacent rod, compressing it and leaving permanent impression. This may be illustrated by the experiment of *Smreker* with wax sticks. He put wax

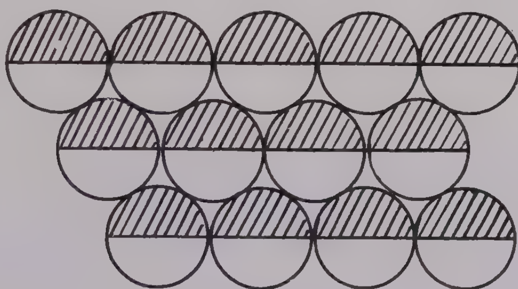


Fig. 5
Arrangement of wax sticks in Smreker's experiment. The dark half of each stick is of soft, the light, of hard wax.

sticks together in such a way that half of each stick was soft and half hard. Fig. 5. He warmed them a little and pressed them together, so that the harder portion made an impression in the softer. In cross section these produced the scale-like shape shown in Fig. 6. When the wax sticks were arranged differently, varying shapes of rods could be produced. From Fig. 7 we can see that this experiment corresponds to conditions in actual enamel formation. This photograph shows a decalcified section of poorly calcified enamel with scale-like rods. The cementing substance is indicated by the dark lines. The calcified portions of the enamel rods are lost in the preparation, and

appear as clear white spaces. The dark areas at the angles of the scales are uncalcified organic substances in the rods, which do not disappear by decalcification. This shows that *the calcification of human enamel rods begins at the periphery of each rod and proceeds toward the center. The calcification begins earlier on one side than on the other.* (See Fig. 4.)

This order of development is not found in dog's teeth. Fig. 8 indicates that calcification begins on the whole circumference of the rod simultaneously. The interprismatic substance is to be seen as dark lines. Next follow light spaces representing the

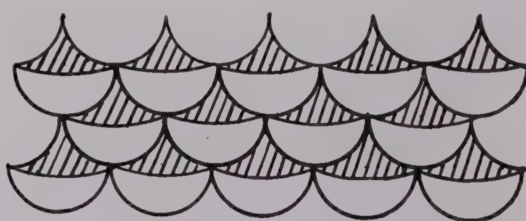


Fig. 6
After softening and pressure of the wax sticks, a cross section shows a scale like formation.

calcified portions of the rods which have been lost by decalcification. The dark stained centers are uncalcified organic areas of the rods. The pressure accompanying growth has not compressed one side more strongly than the other but has been exerted equally about the rod. Of course variations in rod formation may be seen in both species; the scale-like rods in dog's teeth, and the more rounded rods in human teeth.

Enamel epithelium

The enamel is a product of epithelium. It is not my purpose to discuss here the development of the teeth, but I will limit myself to the description of the enamel organ, the function of which is to produce enamel, and after enamel is completely built, to protect it from connective tissue which might damage it. Fig. 9

shows a tooth germ in which formation of dentin and enamel has not yet begun. Four layers may be distinguished in the epithelial enamel organ. *The outermost layer* is composed of cuboidal cells and is known

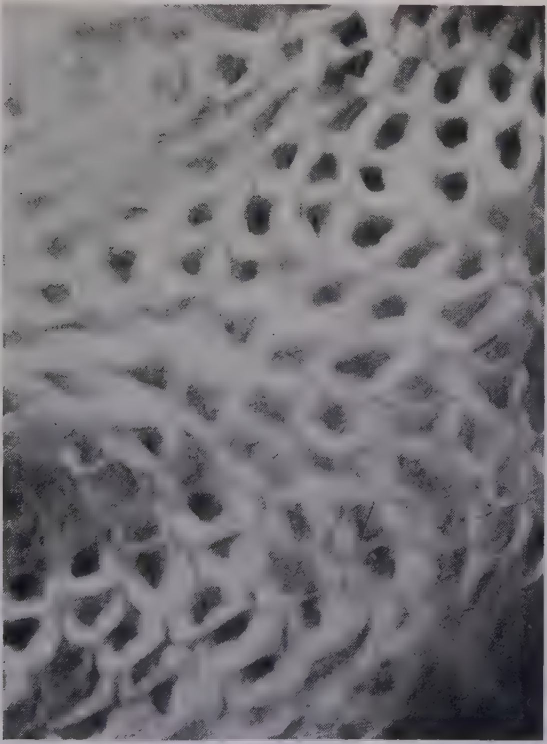


Fig. 7
Decalcified section of poorly calcified enamel. The dark lines are cementing substance; the light spaces the calcified parts of the enamel rods. The dark dots in the angles of the scales are poorly calcified areas in the rods.

as *the outer enamel epithelium.* The layer next to the outer epithelium is the *stellate reticulum* which consists of epithelial cells widely separated by fluid. The cells are connected with long intercellular bridges.

The innermost layer of cells are cylindrical in form and constitute *the inner enamel epithelium.* These are the cells which build the enamel, and are called ameloblasts or "*ganoblasts*" (*Schaffer*). The latter term is to be preferred and will be used hereafter. The ganoblasts are not in direct contact with the

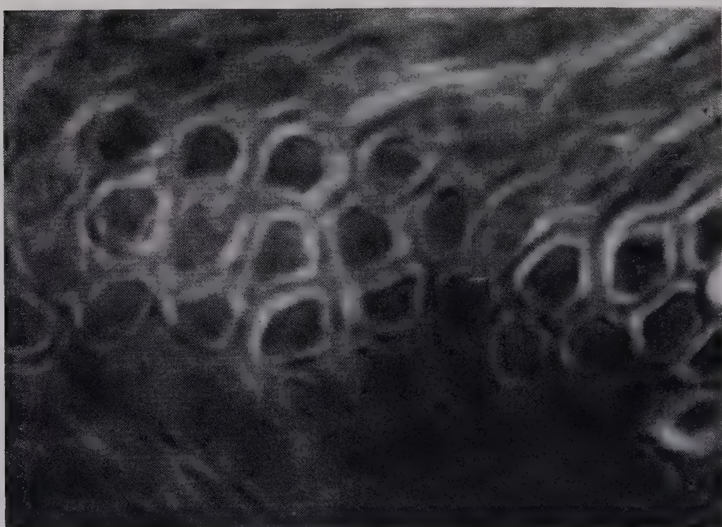


Fig. 8
Calcification in dog's enamel starts on whole circumference of each rod.

stellate reticulum,—but are separated from it by a layer of epithelial cells of cuboid shape, *the stratum intermedium.* Fig. 10 illustrates the four layers under high magnification.

The enamel is formed by the ganoblasts. *Each ganoblast builds one enamel rod from the dento-enamel junction to the surface of the enamel.* At a certain stage of development *protoplasmic processes* are seen *projecting from the central ends of the ganoblasts*—the so-called *processes of Tomes.* The *Tomes'* processes are young

Tomes processes

uncalcified enamel rods, in other words they constitute the organic matrix of the rods. The inner ends of the ganoblasts are connected with each other by

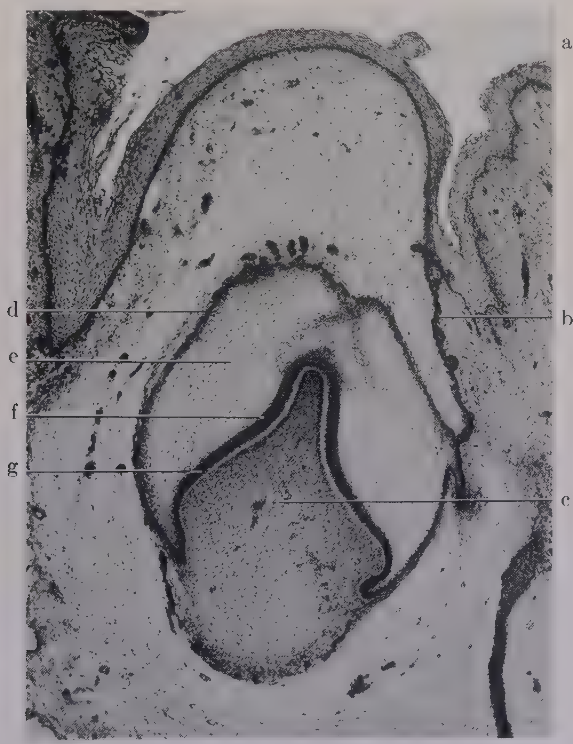


Fig. 9
Toothgerm of a 102 mm. human embryo.

a. mouth cavity.
b. dental lamina.
c. dental papilla.
d. outer enamel epithelium.
e. stellate reticulum.
f. stratum intermedium.
g. inner enamel epithelium or ganoblasts.

Terminal bars

the so-called terminal bars, as shown in Fig. 11. These are the thickened[1] ends of the intercellular substance. The intercellular spaces are closed by the terminal bars. In sections the terminal bars show as dots,

[1]By "thickening" is implied an increase in density.

but in a three dimensional reconstruction they appear as frames surrounding the ends of the cells. This is shown by diagram Fig. 12. Between the terminal bars the processes of *Tomes* project as elongations of

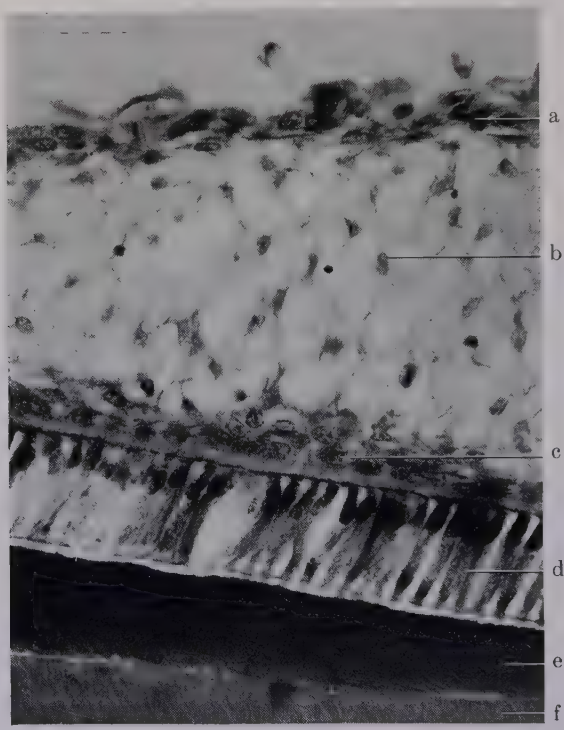


FIG. 10
Enamel epithelium.

a. outer layer.
b. stellate reticulum.
c. stratum intermedium.
d. ganoblast layer.
e. enamel.
f. dentin.

the bodies of the ganoblasts. Diagram Fig. 13 illustrates this. Opposite the processes, as shown in Fig. 11, a honey-comb layer may be observed. This is the network of cementing substance from which the *Tomes* processes have been torn during the preparation.

This network corresponds to the terminal bars. This is further illustrated in the two following photographs.

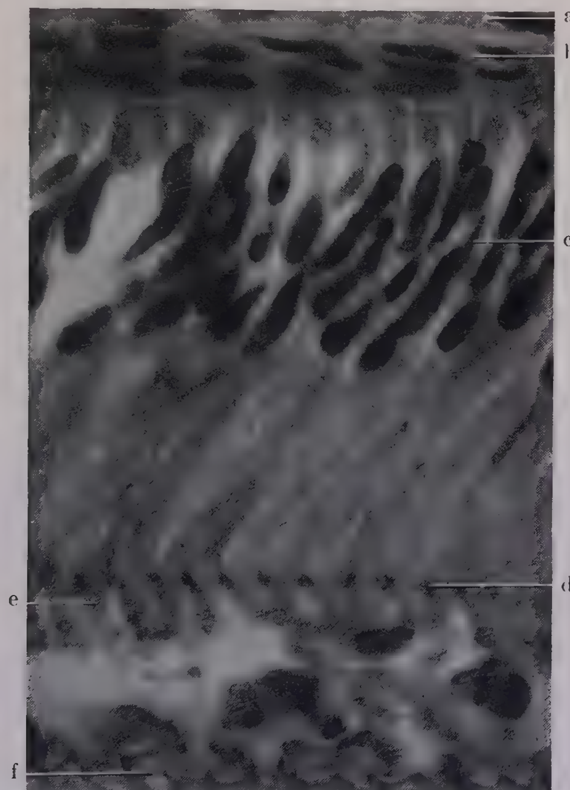


Fig. 11

Enamel epithelium. The Tomes processes are torn from the cementing substance.

a. outer enamel epithelium.
b. stratum intermedium.
c. ganoblasts.
d. terminal bars.
e. Tomes processes.
f. cementing substance.

In Fig. 14 we find a tear between the ganoblasts and the enamel. The young enamel rods—the *Tomes* processes—have been torn from the ganoblasts and remain attached to the older part of the enamel. The

part remaining connected with the ganoblasts in this specimen constitutes the interprismatic or cementing substance. From this photograph one cannot decide to which portion of the ganoblasts the cementing substance corresponds. This may be seen clearly in the following photograph. Fig. 15 shows that the

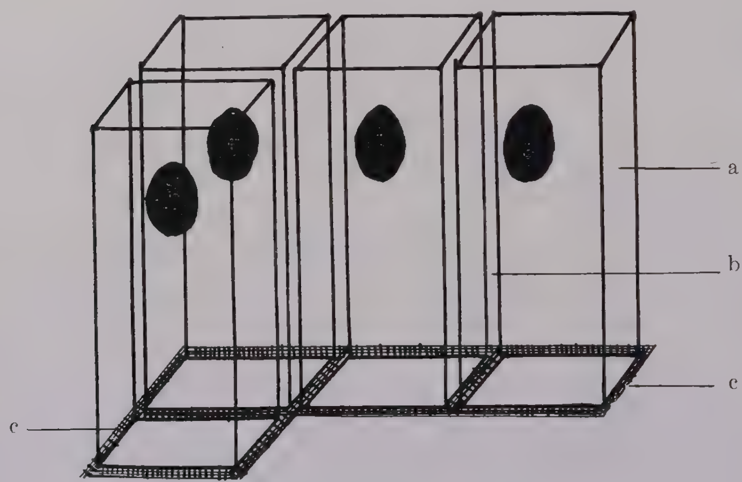


Fig. 12
Diagram of ganoblasts (a)
b. intercellular substance. c. terminal bars.

interprismatic substance seen as fibers arises from terminal bars found between the inner ends of the ganoblasts. In this specimen the enamel was lost during decalcification.

The photomicrographs show the relation between the different portions of the cells in one plane only, which is the reason that the terminal bars are seen as dots. Fig. 12 illustrates the terminal bars as frames surrounding the ends of the ganoblasts, which appear in photomicrographs as dots. If we imagine the photographs reconstructed in three dimensions as in Figs. 12 and 13 it will be clear that the terminal bars

are frames, and *the cementing substance* which appears in section as fibers *are* really sheaths, *elongations of the frame-like terminal bars.* Lams was the first to emphasize the importance of the terminal bars in the building of enamel. The *Tomes processes are protoplasmic processes of the ganoblasts, that is, young uncalcified rods*, the calcification of which extends from

Cementing substance

Rods

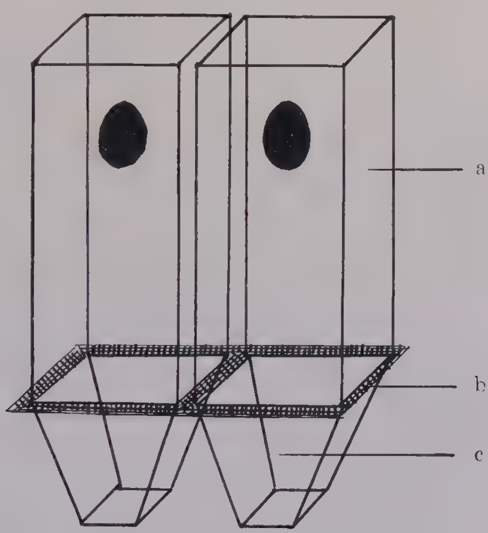


Fig. 13
Diagram of ganoblasts (a)
Tomes processes (c) Terminal bars (b)

the outside toward the center, as shown in Fig. 3. Before the calcification of the enamel begins, each rod is a protoplasmic process of a ganoblast. As calcification begins, the calcium salts are first deposited in that portion of the rod lying farthest from the cell. At the same time calcification proceeds from the periphery of the rod towards the center, illustrated in Fig. 16. The part of the protoplasmic processes nearest the cells remains uncalcified the longest as

Tomes processes. As the building of the enamel proceeds and the rods become longer, more and more of the processes become calcified, but always at points

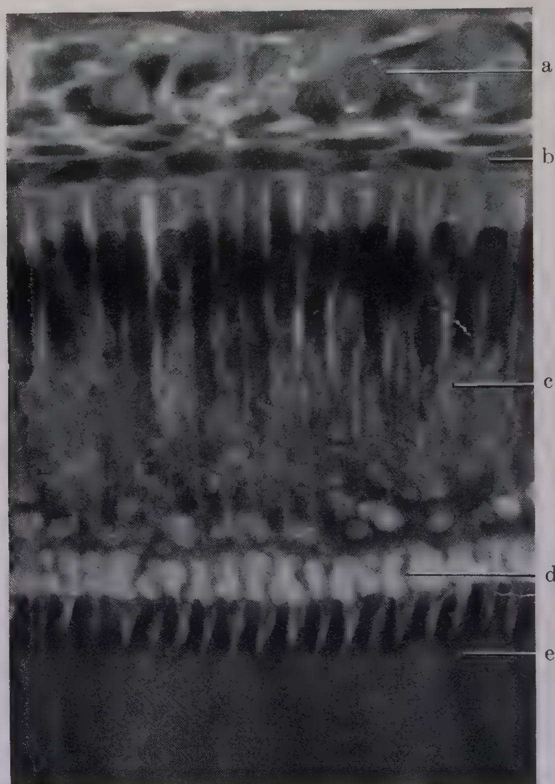


Fig. 14
Enamel epithelium. The cementing substance is torn from between the rods.
a. outer layer. c. ganoblasts.
b. stratum intermedium. d. cementing substance.
e. enamel.

farthest from the cells. On the inner end of the cells new portions of the rods are being continually built as protoplasmic processes. When enamel formation

ceases, these last portions of the rods—the *Tomes* processes—also calcify.

Every enamel rod has its corresponding ganoblast, and the interprismatic substance corresponds to the

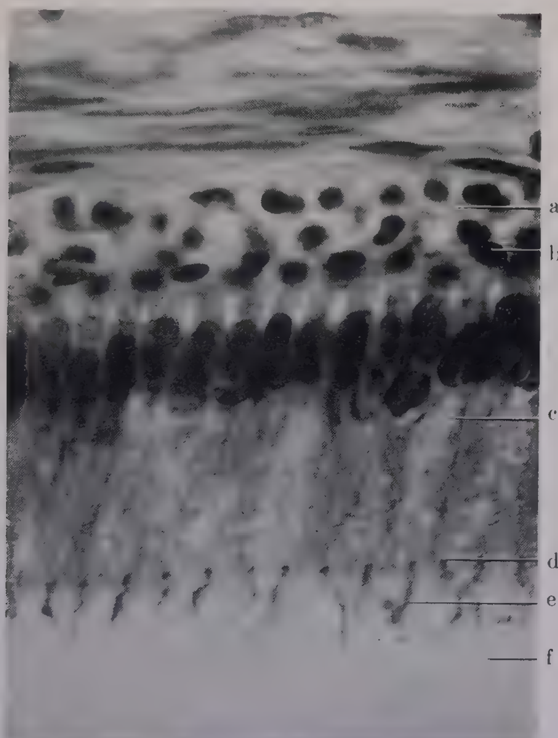


Fig. 15
Enamel epithelium. The cementing substance extends from the terminal bars.

a. outer layer.
b. stratum intermedium.
c. ganoblasts.
d. terminal bars.
e. cementing substance.
f. enamel.

intercellular substance—the terminal bars. Each enamel rod is built by one and the same ganoblast. This statement requires explanation because it is not generally accepted. The enamel rods are not parallel but cross

each other as shown in Fig. 17. *The crossing of groups of rods presents the appearance of the so-called Schreger's lines.* If we make cross sections through the enamel, we cut groups of rods in different directions, some obliquely and some tranversely, as shown in Fig. 18

Schreger's lines

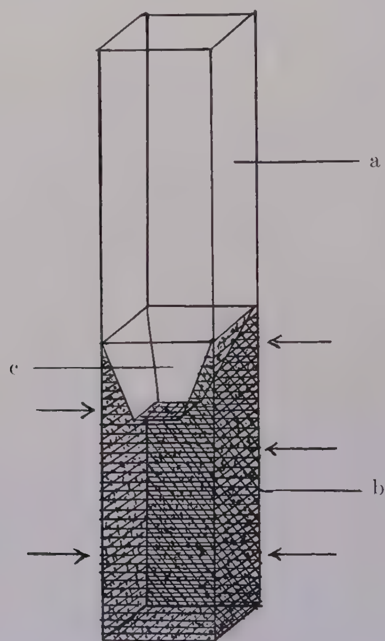


FIG. 16
Diagram showing course of calcification and origin of Tomes processes.
a. ganoblast. b. calcified rod.
c. uncalcified portion of rod—Tomes process.
The arrows indicate the course of calcification.

in low and in Fig. 19 in higher magnification. A most striking example of the crossing of rods may be seen in the enamel of the incisors of rats Fig. 20. However, not only do rods cross each other but the cells also, during formation of the rods Fig. 21. The

fact that ganoblasts may cross each other during development of the enamel offers the best explanation for the development of twisted rods or the so-called

Fig. 17
Crossing of enamel rods.
a. enamel. b. dentin.

Gnarled enamel

gnarled enamel. The crossing of the rods does not exclude the possibility that each rod has been built from beginning to end by the same cell.

The surface of the enamel is greater than the surface

of the dentin; therefore the rods must have either a larger outer diameter, or there must be short rods which fill in the spaces on the greater outer surface of the enamel. Investigations tend to prove that there are no such short rods, but that every rod not only extends from the dentin to the outer surface of the enamel, but that they become wider in diameter as they ap-

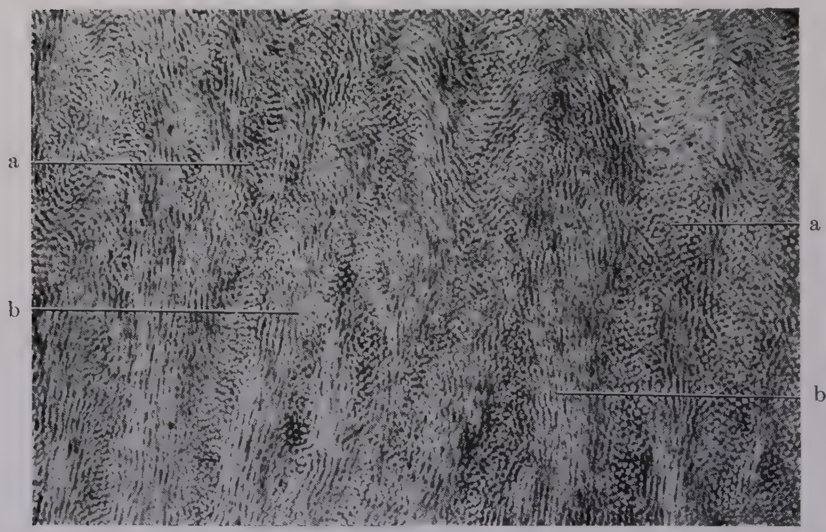


Fig. 18
Schreger's lines. Human enamel, grinding.
a. enamel rods tranversely sectioned.
b. longitudinally sectioned.

proach the surface and in this way compensate for the larger outer surface, (*Pickerill*, *Williams*, *etc.*) The diameter of the rods varies in different cases between 3 and 6 micra. No cell division can be seen in the ganoblast layer after the enamel has begun its formation. If new interposed short rods were built, as some authors state, new ganoblasts also would have to be built. This formation of new cells can take place only by cell division of old cells or the neighboring

cells of the stratum intermedium. Thus far this cell division has not been observed after enamel formation has commenced. Cell division may be observed in the ganoblast layer only in those areas where enamel formation has not yet begun. In Fig. 22 cell division is to be seen at the border of the ganoblasts and stratum intermedium. Apparently cells are being crowded

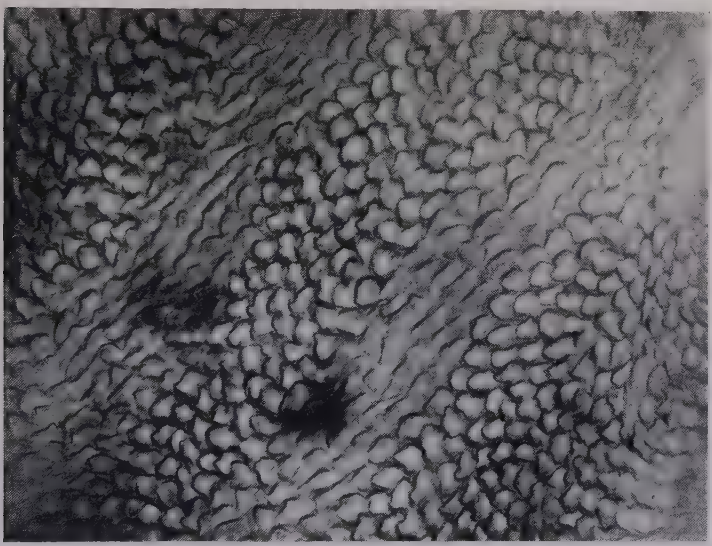


Fig. 19
Schreger's lines in higher magnification. Tranverse and longitudinal section of groups of rods.

into the ganoblast layer from the intermediate layer. The absence of cell divisions would indicate that no new cells are formed once enamel formation has actually begun, and hence that short rods are an impossibility. From a practical standpoint it is important to know the direction of the course of the enamel rods. In cavity preparation it is necessary to cut the enamel rods in the direction of their long axis and, as *G. V. Black* has pointed out, it is imperative

not to leave any short rods on the outer surface which are not supported on the dentinal junction.

Course of the enamel rods

The best description of the course of enamel rods is given by *G. V. Black* in his Operative Dentistry.

"One of the first things to be noticed is that, when sections are cut parallel with the long axis and per-

Fig. 20
Crossing of rods in rat's enamel.

pendicular to the axial surfaces of the teeth, the enamel rods are cut parallel with their length in every position from the gingival line to, and over, the marginal ridges and cusps of the occlusal surface of the bicuspids and molars, and cutting edges of the incisors. Therefore, in the direction of these sections, the enamel rods are at right angles to the surface of the tooth at all points. The normal and regular deviations from the right angle to the surface are all in the direction of the length

of the tooth so far as the axial surfaces are concerned. These are confined to the approach to the gingival line at the one extreme and the approach to the marginal ridges, cusps and cutting edges at the other. With this view of the case, the whole matter becomes

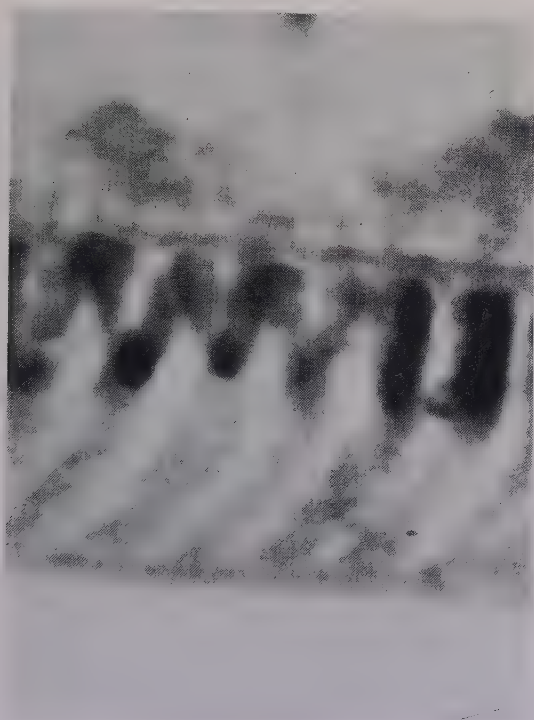


Fig. 21
Crossing of ganoblasts.

simple, and the whole of these variations is shown in five diagrams. While this is true as the statement of a general fact of normalcy that may be taken as the working basis of action in the preparation of cavities, it must not be forgotten that there are frequent variations from the normal direction of these rods

which must be found by noting the direction of cleavage, or feeling for it, as hereafter described." As *Black* expresses it, areas of gnarled rods in the enamel are like pine knots in wood. They do not split and cause difficulty in cavity preparation. This gnarled or twisted enamel occupies the inner layer of the

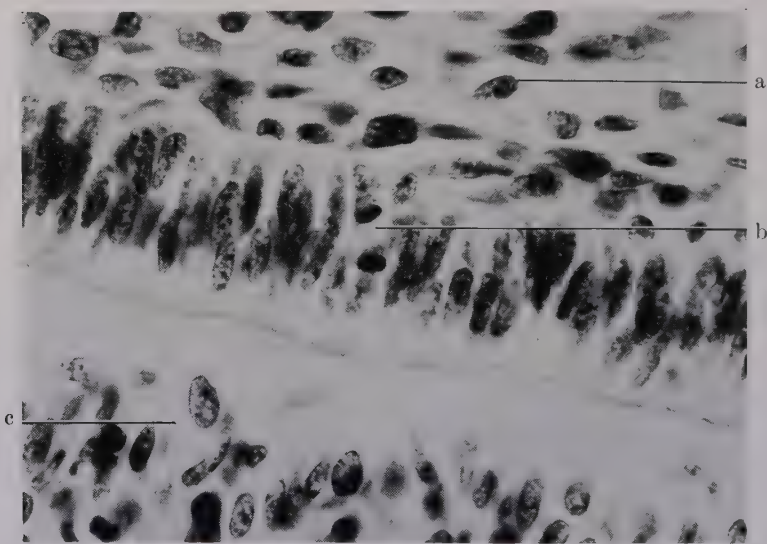


FIG. 22
Cell division in enamel epithelium.
a. stellate reticulum.
b. cell division on the border of the stratum intermedium and ganoblasts.
c. pulp.

enamel. On the outer surface the rods, for the most part run regularly.

Enamel Organ

The enamel organ does not show the same appearance during the whole development of the enamel.

The following photographs illustrate the different stages of change in the enamel epithelium up to the beginning of eruption of the teeth. Fig. 23 shows all four layers of the enamel organ; ganoblasts, stratum

intermedium, stellate reticulum, and the outer enamel epithelium. In a later stage, Fig. 24, the stellate reticulum does not have the same structure as before. The outer epithelium seems to take the place of the

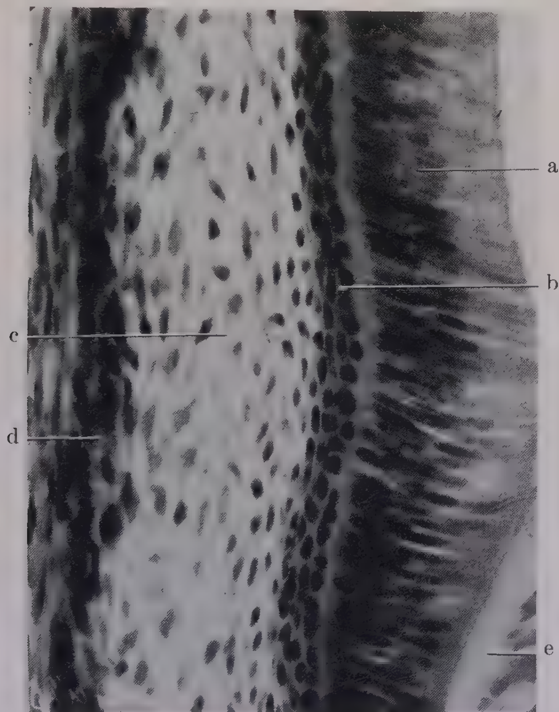


FIG. 23
Enamel epithelium.
a. ganoblasts. c. stellate reticulum.
b. stratum intermedium. d. outer enamel epithelium.
e. enamel.

stellate reticulum, and approximates the stratum intermedium. Later still (Fig. 25), the stellate reticulum has entirely disappeared, and the stratum intermedium and the outer epithelium are in contact. After the stellate reticulum has disappeared and outer

epithelium, stratum intermedium, and ganoblasts are in contact, we call the enamel epithelium the "united enamel epithelium." (*G. Fischer*). In another picture, Fig. 26, the blood vessels are plainly seen. They lie

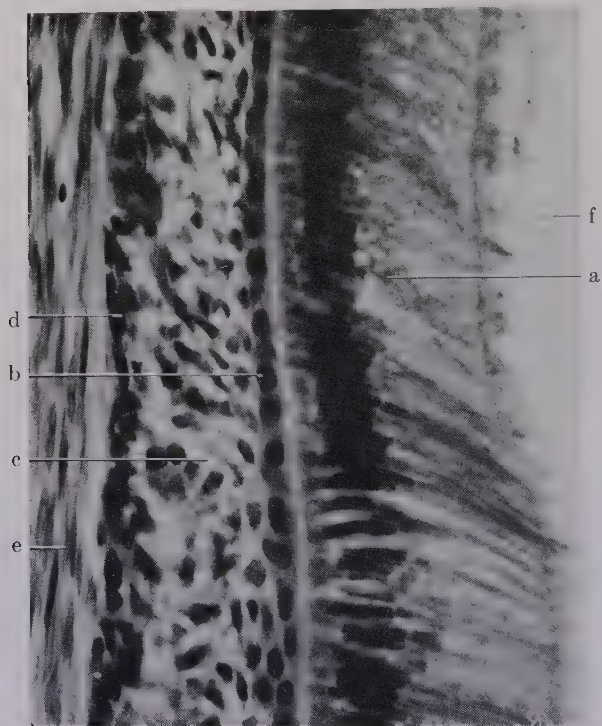


Fig. 24

Enamel epithelium. The stellate reticulum (c) is changed in structure.

a. ganoblasts.
b. stratum intermedium.
d. outer enamel epithelium.
e. connective tissue around the enamel epithelium.
f. enamel.

United enamel epithelium

in the connective tissue papillae which project into the outer enamel epithelium. *It is important to note that the capillaries do not enter the human enamel organ.* Before the stellate reticulum disappears, the blood

vessels end in loops close to the outer surface of the outer epithelium. The stellate reticulum is free from blood vessels. In some animals, for instance the rat,

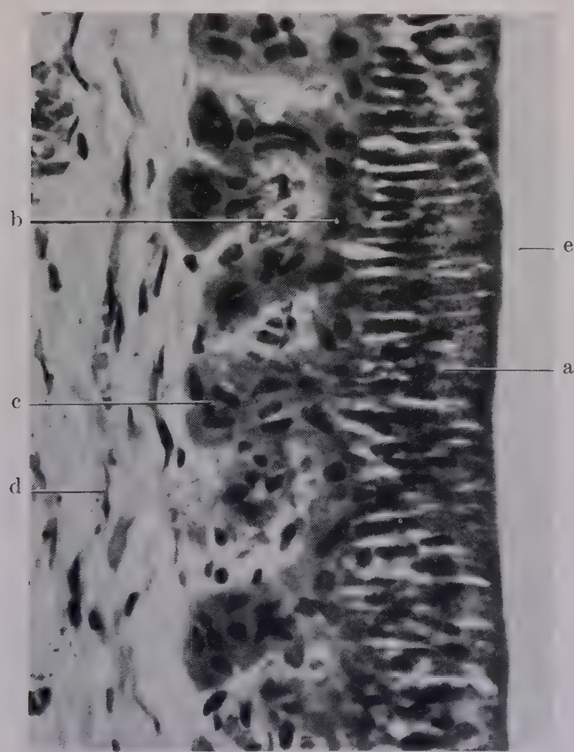


Fig. 25
The stellate reticulum has disappeared and the outer enamel epithelium (c) and stratum intermedium (b) lie in connection with the ganoblasts (a) a, b, c united enamel epithelium. d. connective tissue. e. enamel.

the stellate reticulum has blood vessels in the molars (*Addison and Appleton*) not in the incisors.

After the ganoblasts have almost completed their function, they lose their cylindrical shape and become

more cuboidal, Fig. 27. Shortly after this stage no distinction can be made between the various kinds of epithelial cells lying on the surface of the enamel, Fig. 28. It appears as though this epithelium originates largely from the stratum intermedium, and that the

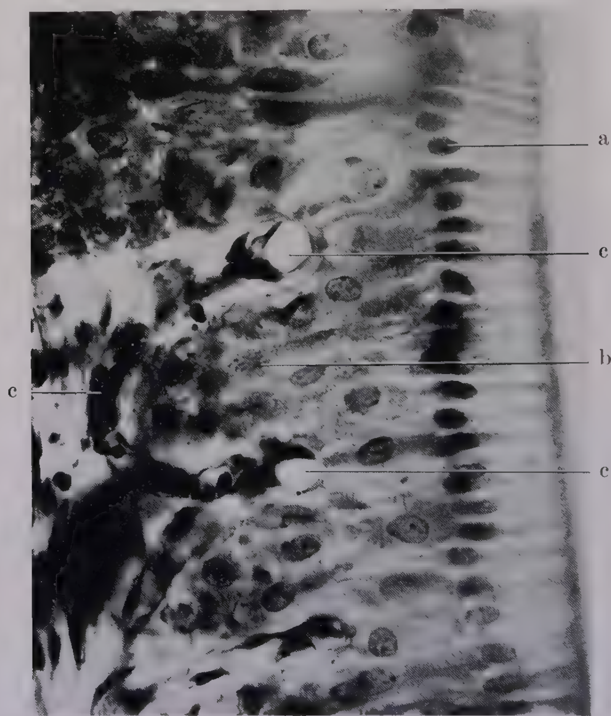


Fig. 26
Blood vessels (c) in the connective tissue outside of the outer enamel epithelium (b). a. ganoblasts.

outer enamel epithelium contributes little to this layer. Fig. 29 shows the relative thickness of the two layers. The stratum intermedium is composed of many layers, while the outer enamel epithelium consists of but a single layer of cells. In other cases the relationship

between the two layers appears to be reversed; that is, the stratum intermedium seems to be less active in the development of the epithelial layer covering the surface of the enamel after the ganoblasts have dis-

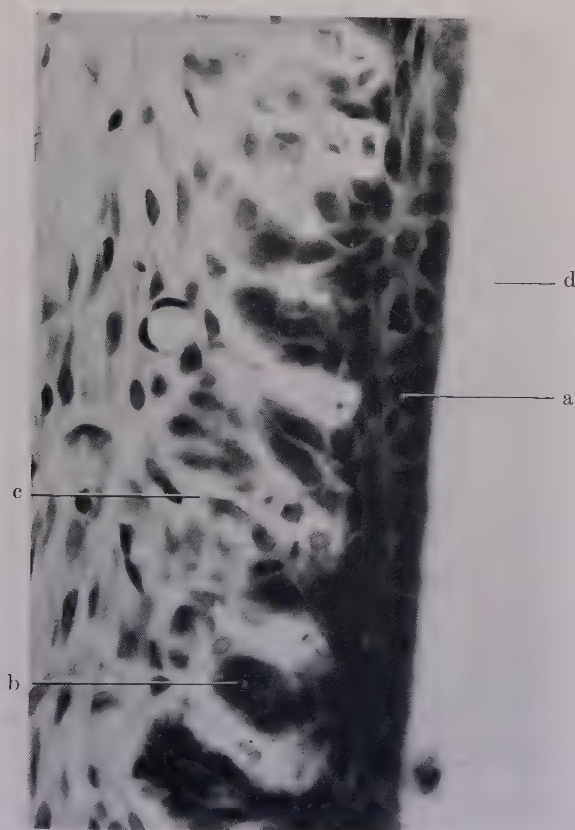


FIG. 27
Cuboidal shape of ganoblast (a).
b. outer enamel epithelium and stratum intermedium.
c. connective tissue. d. enamel.

appeared. This epithelium built by the stratum intermedium and the outer epithelium will be called in further description the "reduced" enamel epithelium. *"Reduced" enamel epithelium*

(Fig. 28.) It resembles the stratified squamous epithelium of the mouth.

Finally *the last product of the ganoblasts is a cuticle.* This is to be seen in Fig. 30. *This cuticle is an organic membrane which may become calcified the same as the*

Fig. 28
The ganoblasts have disappeared, and only "reduced enamel epithelium" (a) lies on the enamel (c). b. dentin.

Primary enamel cuticle

enamel. Gottlieb named this membrane the "*primary*" enamel cuticle to distinguish it from the "*secondary*" enamel cuticle which forms at the time of tooth eruption. This secondary cuticle is of quite different morphology and histogenesis than the primary cuticle. It is a hornified layer arising from the "reduced"

enamel epithelium which is later called the "epithelium attachment." In the chapter on tooth eruption a more detailed description of the enamel cuticle ("*Nasmyth's* membrane") will be given.

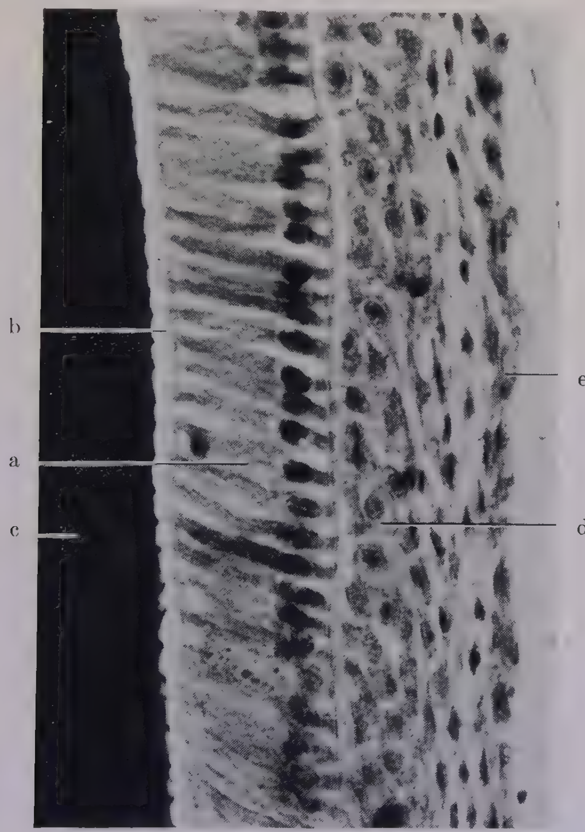


FIG. 29
Enamel epithelium.
a. ganoblasts. b. Tomes processes. c. enamel.
d. stratum intermedium consisting of many layers.
e. outer enamel epithelium consisting of single layer of cells.

There is still considerable discussion in the literature regarding the existence of the cementing sub-

stance and organic material in the enamel as well as the circulation of enamel. *I. L. Williams* stated in 1896 that "normal enamel is completely calcified, con-

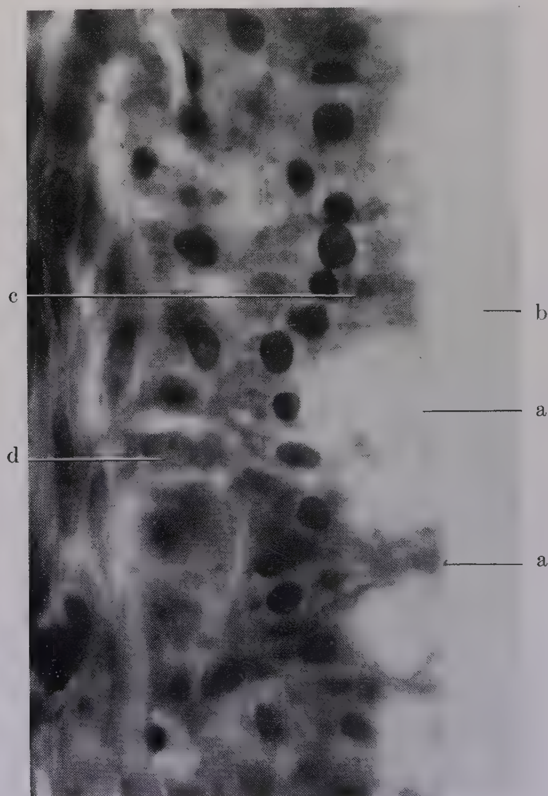


Fig. 30
The primary enamel cuticle (a) is the last product of the ganoblasts (c). b. enamel. d. outer enamel epithelium.

taining no trace of organic matter. No physiologic change is therefore possible in completely formed enamel." *Williams* has since modified his statement in regard to the organic content of enamel. Recent

investigations of *E. W. Fish* have shown that there is a lymph circulation in the organic prism sheath of the enamel (Experiment made on dogs). This prism sheath was first described by *C. F. Bodecker*. *W. J. Gies* has demonstrated that the organic remains of the enamel after decalcification are insoluble proteins which give

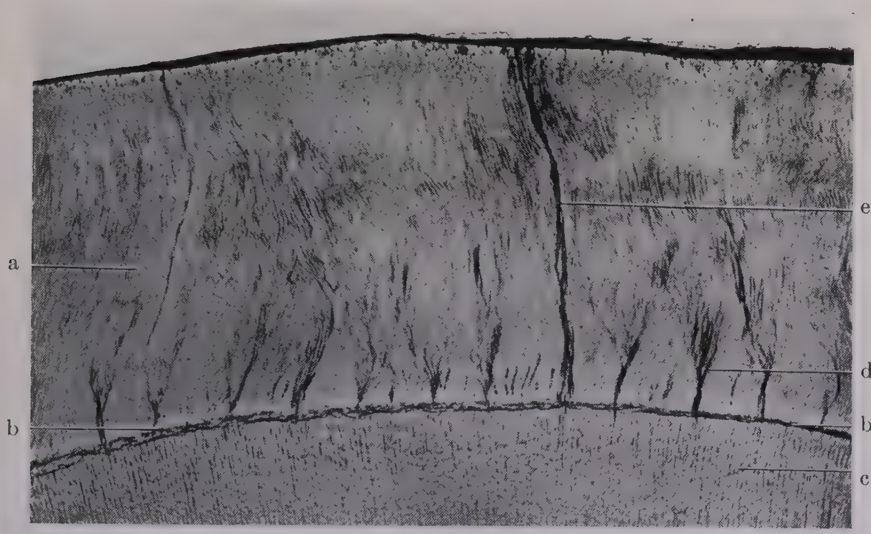


FIG. 31
Grinding.

a. enamel.
b. dento-enamel junction.
c. dentin.
d. "tufts".
e. enamel lamellae.

the biuret reaction. Investigations of *Bunting* and *Rickert*, *Gottlieb*, *Smreker*, *Urbanschitsch*, *Mummery*, and others also indicate that there is a circulation in the enamel. *Theo. Beust* has claimed for years that there is a circulation in the enamel, and these latter investigations partially confirm his claims. *P. Howe* observed in a case of lead poisoning lead deposited in the enamel.

I shall not enter into a minute description of the various statements made in the literature. For this

I refer the reader to the journals. The discussion between *O. Walkhoff* and *V. v. Ebner* only will be mentioned. *Walkhoff* has disputed the existence of an interprismatic or cementing substance between the

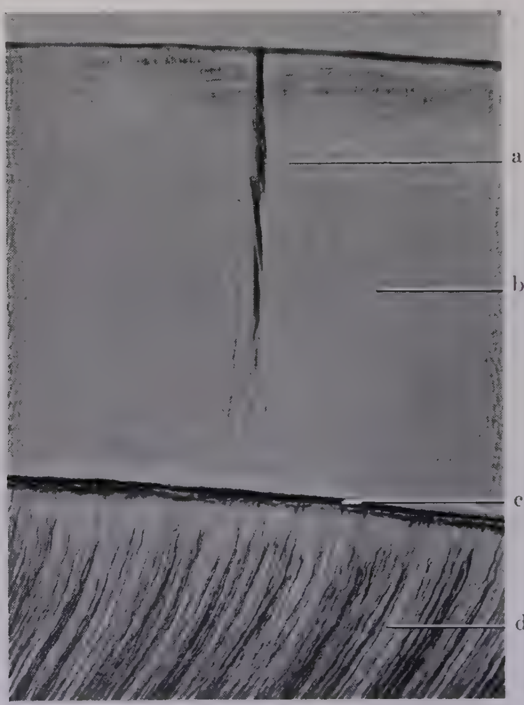


Fig. 32
Enamel lamella (a) consisting of poorly calcified enamel substances.
b. enamel.
c. dento-enamel junction.
d. dentin.

enamel rods; he has stated that the outer portions of the enamel rods are only more poorly calcified than the central portions. *Ebner* held the opinion that an organic substance different from the calcified rods

existed. Since *Ebner* made his statement, it has been indorsed repeatedly.

Well developed enamel shows in its structure not only rods and cementing substance, but also some

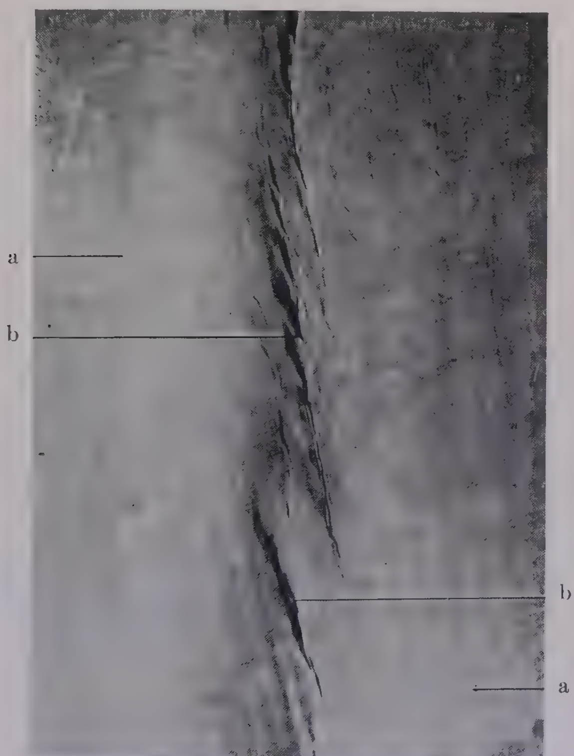


Fig. 33
Higher magnification of Fig. 32.
a. well calcified enamel.
b. enamel lamella, poorly clacified enamel.

structural elements which may be called normal parts of the enamel. These structures are the *enamel lamellae, the so-called tufts, and the spindles.*

The lamellae as first described by *C. F. Bodecker* are *Enamel lamellae*

organic bundles which cross the enamel at right angles to the surface of the enamel as shown in Fig. 31. These run from the surface of the enamel to the dento-enamel junction. Following *Bodecker* many investigators have described these structures differently. Some of them believed that they consisted of uncalcified cementing

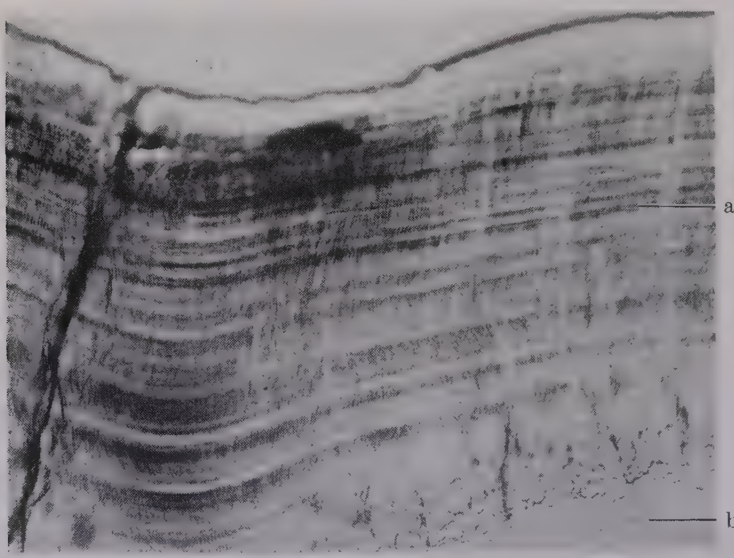


FIG. 34
Stripes of Retzius in enamel.
a. enamel. b. dentin.

substance in the enamel (*V. v. Ebner*). *Walkhoff* described them as poorly calcified rods. For a long time it was thought that they were only artificial crevices in the enamel produced in the grinding. Later investigators showed that this last opinion was a mistake, for the enamel lamellae remained visible after decalcification of the ground specimens. A crevice is a negative appearance, and if the wall of the crevice is lost by decalcification, it should disappear. *Gottlieb* described some of the enamel lamellae as having a

process reaching into the dentin. He called this part the dentinal part of the lamella. *Gottlieb* also stated later that the lamellae are organic substances which originate from the epithelium surrounding the enamel. He observed crevices in the enamel into which the surrounding tissue had grown. He also stated that the outer part of the lamellae may become hornified

Fig. 35
Tranverse striations in the enamel rods.

and concluded from this fact that lamellae were formed from the outer enamel epithelium.

Some time after *Gottlieb's* publications I studied the subject of the lamellae and the tufts and came to the conclusion that many details of histology of these structures still remained to be described. If the lamellae of ground sections and of decalcified sections are

examined carefully, one is forced to the conclusion that *there are two kinds of lamellae.* One of these consists of badly calcified enamel substance, and the other of tissues which have grown into the crevices of the enamel from the surrounding tissue. Fig. 32 illustrates

First kind of lamellae

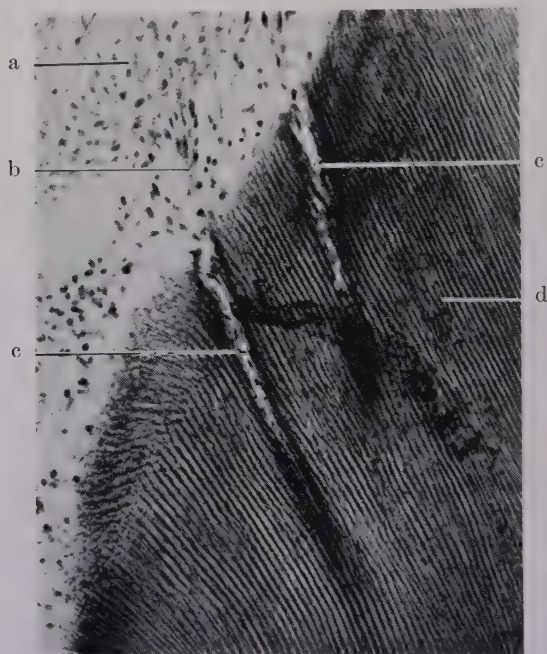


Fig. 36
Crevices (c) in the enamel (d) of a tooth-germ. a. enamel epithelium which grows (b) into the crevices.

the first kind of lamellae consisting of poorly calcified enamel substance. This kind of lamella may penetrate to the dento-enamel junction, but never can reach into the dentin because it is composed only of enamel substance. Fig. 33 is a high magnification of a part of the lamella shown in Fig. 32. We see in the normal enamel structure loosened enamel rods which are poorly

calcified. Poor calcification can be found not only in the rods but also in the cementing substance. I infer that these lamellae originate in the following way: after the whole enamel matrix is completed but calcification not yet finished, microscopic tears may

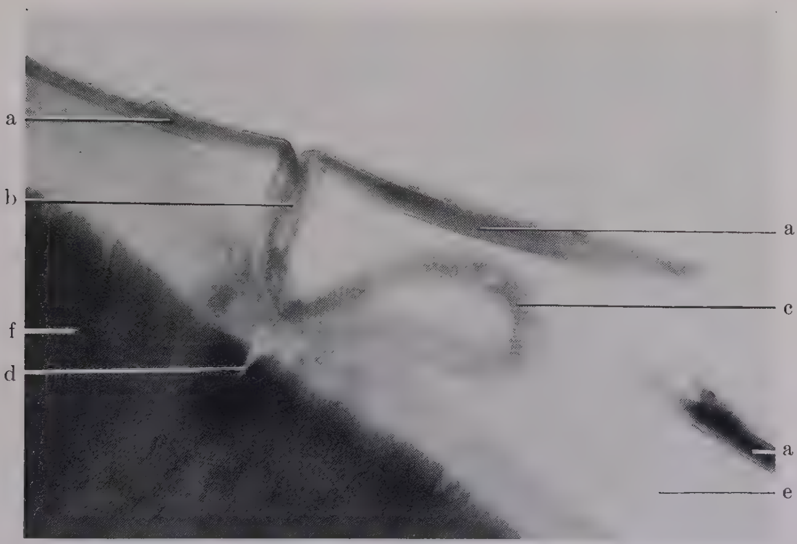


Fig. 37
Enamel lamella, the outer part of which is hornified (b) like enamel cuticle (a). The inner part of the lamella is an organic bundle (c).
d. crevice in the dentin, dentinal part of the lamella.
e. enamel.
f. dentin.
The S shaped form of the lamella is due to shrinkage during decalcification.

develop as a result of pressure in the tissues of the jaw during development. This tear loosens the rods, and in these loosened rods no further calcification takes place, because the connection between the rods is lost. The enamel is a densely calcified substance; therefore it is reasonable to assume that an injury such as a break in the connection of the rods, or any injury at

all, leads to poor calcification. This poor calcification of the enamel cannot be caused by any of the general nutritive diseases, as for example rickets. If this were

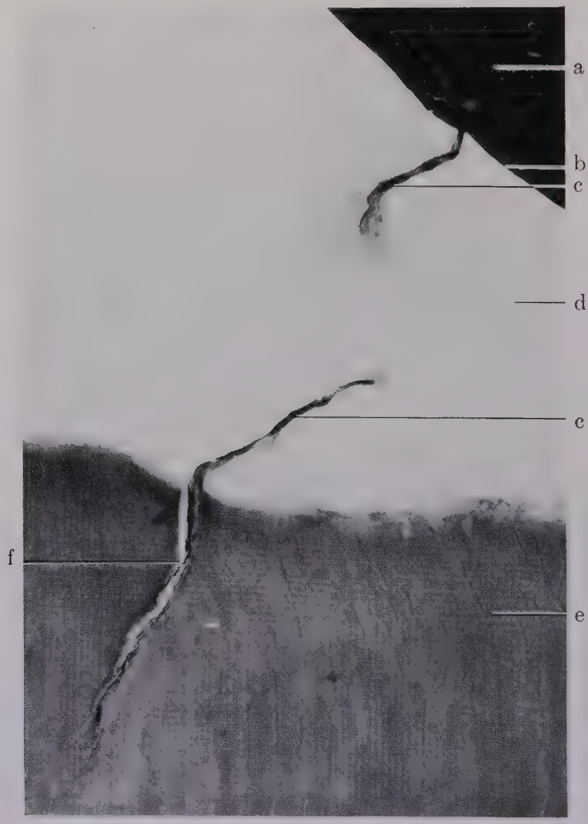


FIG. 38
Enamel lamellae (c) running through the enamel (d) into dentin (e).
f. dentinal part of lamella.
a. epithelium.
b. hornified cuticle.

Stripes of Retzius

the case, incomplete calcification would not be vertical to the surface of the enamel, but parallel to it, as in the stripes described by *Retzius*, (Fig. 34.) The

stripes of *Retzius* are the result of poor calcification of the enamel substance, as well as rods, and cementing substance. These stripes are a record of the developmental history of the individual. At some time during the development of the enamel there was a disturbance of the calcium metabolism, and the part of the enamel

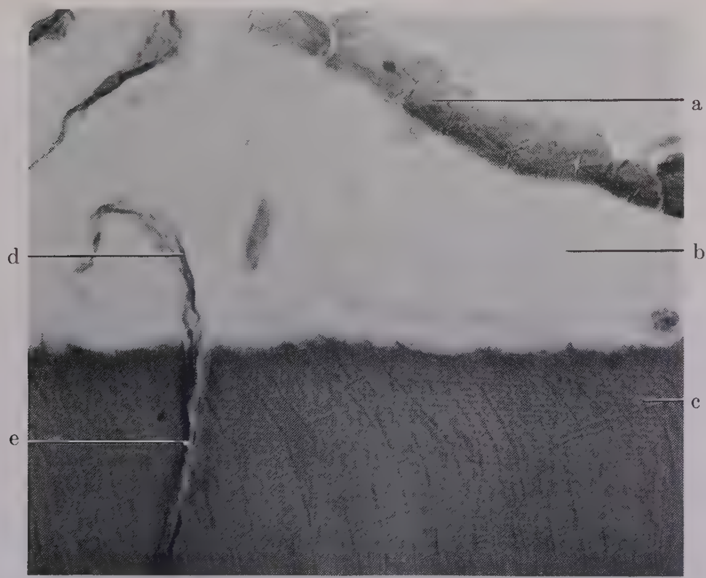


Fig. 39
Enamel lamella (d) with dentinal part (e).
a. enamel cuticle with outline of cells.
b. enamel.
c. dentin.

formed during this period remained poorly calcified. In the region of the lines of *Retzius* we usually observe the so-called transverse striation of the enamel rods. *The transverse striation* as shown in Fig. 35 is a normal characteristic of the enamel rods and is due to an intermittent deposition of calcium salts. Under usual conditions of calcification the transverse striations are

Tranverse striation of the enamel rods

invisible. Only in abnormal calcification or decalcifications do these striations become visible.

Second kind of lamellae

The second kind of lamellae consists of remains of surrounding tissues which have grown into crevices of

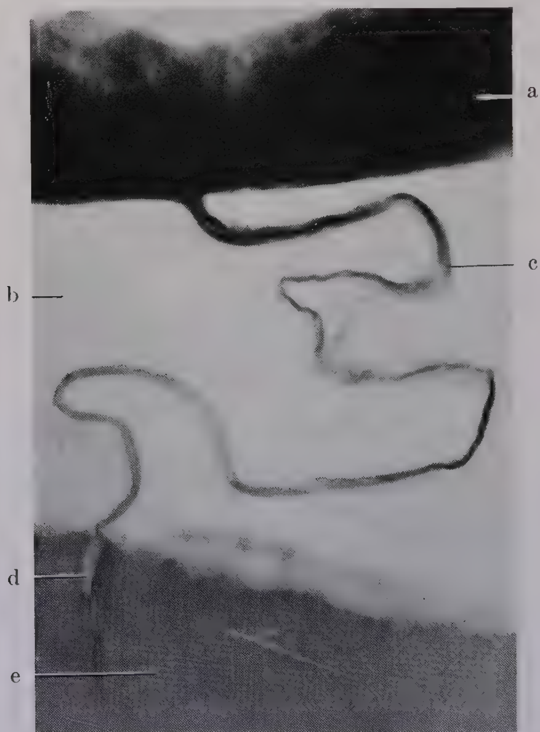


Fig. 40
Enamel lamella, consisting of organic bundle.
a. bacterial plaque.
b. enamel. c. lamella.
d. dentinal part of the lamella. e. dentin.

the enamel. Such crevices in the enamel in a toothgerm are illustrated in Fig. 36. The kind of tissue overlying the crevices determines the substance of this second type of lamellae. Normally, epithelium lies on the surface of the enamel i.e. ganoblasts, stratum inter-

medium, stellate reticulum, and the outer enamel epithelium. The stellate reticulum disappears very

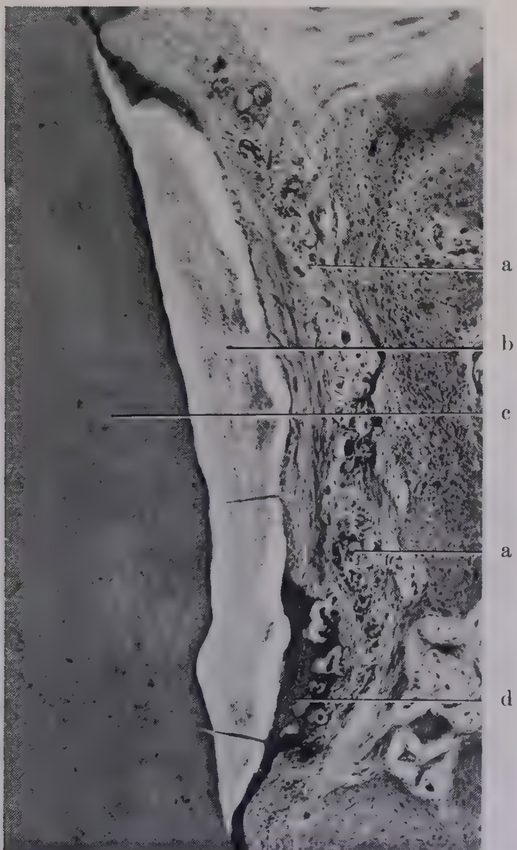


Fig. 41
Enamel drop (b) with lamellae.
a. destroyed enamel epithelium.
c. dentin.
d. cementum on surface of enamel.

early, so that the outer epithelium comes into direct contact with the stratum intermedium. The ganoblasts disappear later also, so that there is only epithelium

lying on the surface of the enamel which is much like the stratified squamous epithelium of the mouth and can become hornified, as we shall see later in the chap-

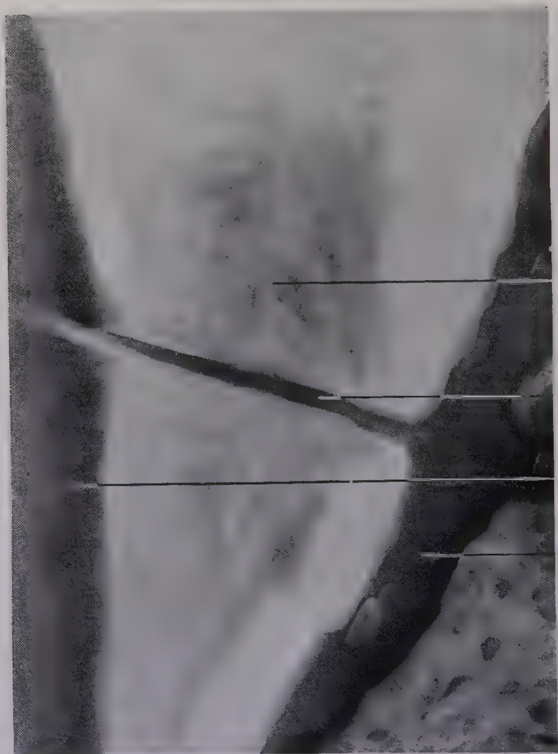


FIG. 42
Higher magnification of an area of Fig. 41.
a. enamel.
b. lamella built by cementum.
c. cementum on surface of enamel.
d. dentin.

ter on tooth eruption. This layer of epithelium which remains on the surface of the enamel after the ganoblasts have disappeared is called "reduced" ename epithelium.

If tissue from the "reduced" enamel epithelium lies on the surface of the enamel and grows into a crevice, the lamella may become hornified just as may the enamel cuticle. The tears in the enamel seem to arise at the time when the reduced enamel epithelium and also the ganoblasts lie on the surface of the enamel; there the lamellae generally originate,

FIG. 43
"Fibers" of the "tuft" (b) running to the right.
a. enamel. c. dentin.

not only from the stratified squamous epithelium, but also from the inner epithelium (i.e. ganoblasts). The former is capable of hornification; the latter seems not to be. This second kind of lamellae can consist of two parts. The inner part can be built by an organic substance arising from the inner epithelium; the outer part can originate from the stratum intermedium and outer enamel epithelial layer, and may become hornified, as illustrated in the next photograph, Fig. 37. In this photomicrograph the hornified cuticle can be seen on the surface of the enamel which has disappeared

through decalcification. The cuticle can be traced to the entrance of the lamella, so that the outer part of the lamella is formed of a double layer of cuticle. The inner part of this lamella is not hornified—it is an organic bundle which has probably originated from the inner enamel epithelium. A wedge-shaped crevice also may be seen in the continuation of the lamella in the dentin in this figure. This is the dentinal part of the

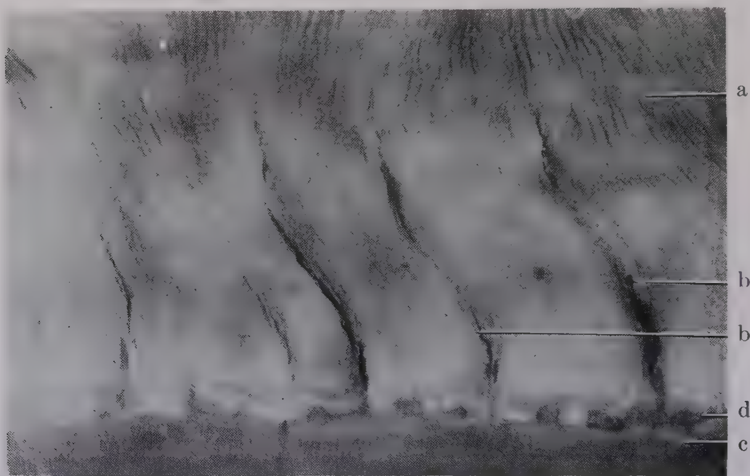


Fig. 44
"Fibers" of the "tuft" (b) running to the left.
a. enamel. c. dentin. d. dento-enamel junction.

Dentinal part of the lamellae

lamella, described by *Gottlieb*. This statement was disputed by a number of authors who asserted that these crevices in the dentin were artefacts. However, it has been proven that the dentinal part of the lamella does exist. The difference of opinion undoubtedly was due to the fact that the authors did not recognize the two kinds of lamellae. The first kind of lamella as shown in Figs. 32-33 cannot have a dentinal portion, but the second kind of lamella can. This is demonstrated also in the following photomicrographs. Fig.

38 shows a lamella near the cemento-enamel junction crossing the enamel and reaching into the dentin. The lamella shows a tear caused in the preparation of the specimen. We observe not only a crevice in the dentin, but see also a part of the lamella reaching into it.

A similar case is shown in Fig. 39. It may be mentioned that the cuticle in this case is not homogeneously hornified, for the outlines of the cells of the reduced

FIG. 45
Diagram of a "tuft" in low magnification. All the fibers may be seen at once.

enamel epithelium may be seen. The lamella crosses the enamel and reaches also into the dentin. It is to be noted that the dentinal part of the lamella crosses the dentinal tubuli. This constitutes proof that the lamella originated after the dentin was laid down.

The statement was made previously that the second kind of lamella consists of tissues which have grown into crevices of the enamel as well as crevices at the dentin. These lamellae may be composed of various kinds of tissues depending on what types of tissue overlie the crevices. If the cells of the inner epi-

thelial layer lie opposite a crevice, the lamella becomes an organic band as seen in Fig. 40. In this case the cells of the reduced epithelium layer have either not grown into the crevice or have not become hornified. If connective tissue lies opposite the enamel when a crevice arises, the connective tissue grows into the crevice and forms a lamella. Connective tissue may occasionally be found lying on the surface of the enamel; this occurs when for any reason the enamel epithelium has been destroyed. Connective tissue is capable of

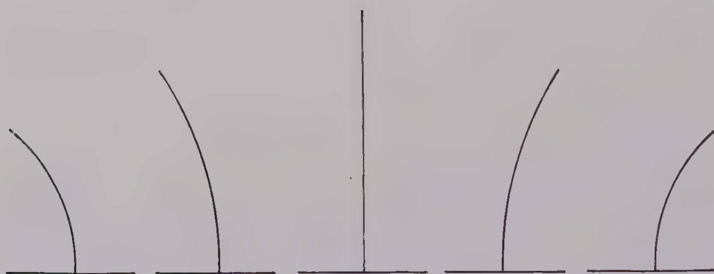


FIG. 46
"Fiber" of the tuft in high magnification. One fiber only may be seen at once.

producing bone and cementum. We see in the following picture, Fig. 41, an enamel drop on the root of a human molar. The enamel epithelium has been destroyed. Connective tissue lies on the surface of the enamel drop, and some lamellae may be observed penetrating the enamel. A higher magnification, Fig. 42, shows one of these lamellae. It is quite evident that the cementum penetrating the enamel is a continuation of the cementum overlying the enamel. This cementum lamella extends also into the dentin.

To recapitulate; there are morphologically two kinds of lamellae; one of which consists of poorly calcified enamel substance, the other of cell remnants which have grown into the crevices of the enamel from the surround-

ing tissues. However, in their development I am inclined to think that the differences are only a variation of intensities of the same process. After the enamel is completely laid down but not yet fully calcified, loosening of the rods may result from pressure which always accompanies developmental growth. These loosened rods remain uncalcified and constitute the first order of lamellae. If the pressure which in one case brings about the loosening of the enamel rods

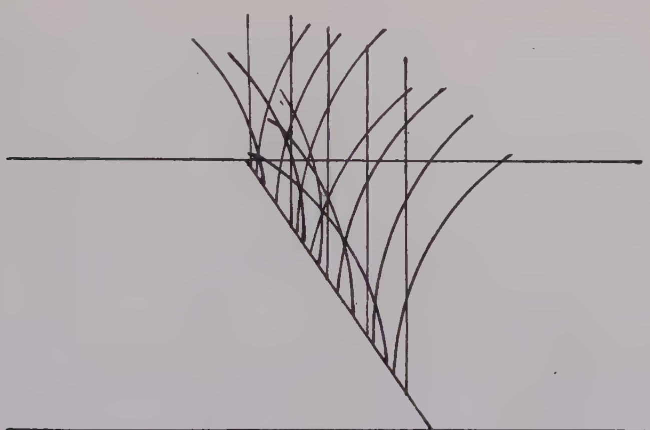


FIG. 47
A "tuft" in perspective view.

becomes stronger, crevices result, and the surrounding tissue grows into them. This constitutes the second kind of lamellae. This class of lamellae may become hornified, mostly on the outer portion, and may consist of organic bundles or cementum, depending upon what kind of tissue overlies the crevices.

Enamel Tufts

Other structures in the enamel are the so-called "tufts". The tufts arise from the dento-enamel junction and spread into the enamel to about a third of its thickness. These structures are studied best in ground sections as shown in Fig. 31. The tufts as they are described

and shown in the preceding picture have not in reality a *tuft-like shape*, but this shape *is an optical phenomenon.* If a so-called tuft is examined under low magnification the entire thickness of the specimen may be seen at once, and consequently we have a resemblance of a tuft. However, if "tufts" are observed under high magnification the tuft-like structure cannot be seen.

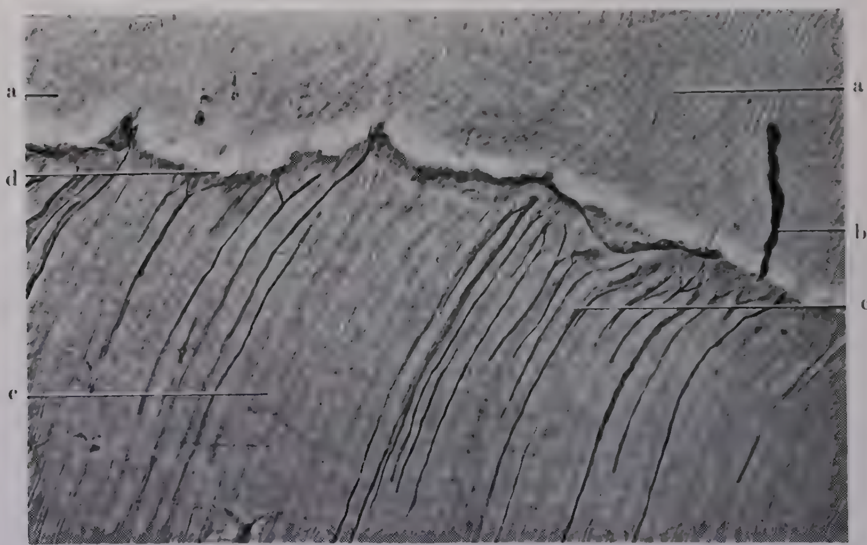


FIG. 48
Scallop-like dento-enamel junction (d).
a. enamel. b. enamel spindle. c. dentin.

With high power objectives the entire thickness of a specimen cannot be seen at once, but can be studied only by plane as the objective is focussed. One plane only is in focus at a time. The following illustrations will show these facts.

Fig. 43 shows the "fibers" of the tufts running to the right, while Fig. 44 shows them running to the left. The two photographs are taken from the same specimen in different planes. *The different fibers of*

the tufts do not lie in the same plane, and they do not start at the same point from the dento-enamel junction. The tuft-like shape is brought about by the projection of fibers lying in different planes into one plane by the low magnification. The following diagrams may be helpful to make this clear. Fig. 45 is a diagram of a "tuft" as it appears in low magnification. The next picture,

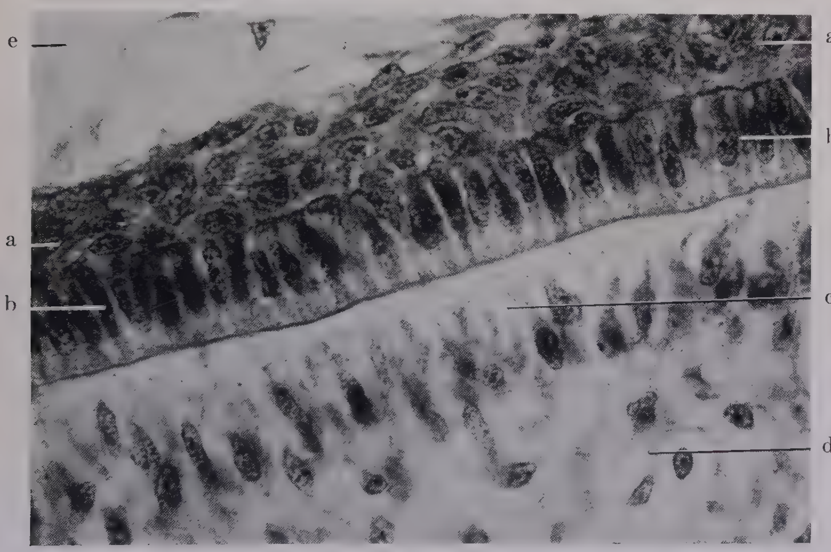


FIG. 49
The ganoblast (b) and odontoblast (c) lie in contact before dentin and enamel are built.
a. stratum intermedium. d. pulp. e. stellate reticulum.

Fig. 46, shows the fibers of the tuft in high magnification. We can see only one fiber at a time, and must focus deeper with the objective to see the next one. In a perspective drawing the so-called "tuft" appears as in Fig. 47. The line on which the fibers end at the dento-enamel junction is almost always parallel to the axis of the tooth; therefore the tuft-like shape is almost never seen except in horizontal grindings. Apparently

Theo. Beust holds a similar view regarding the arrangement of the fibers of the tufts.

The fibers of the tuft-like structures are not real fibers, but enamel rods and cementing substance more

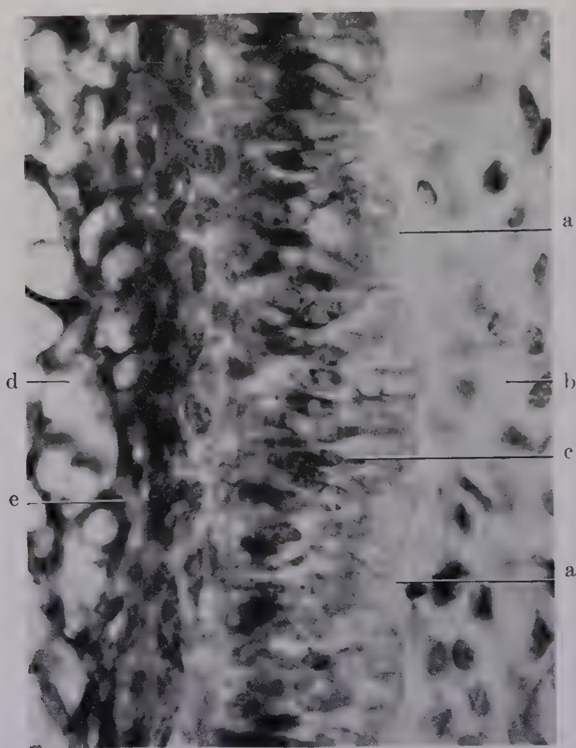


Fig. 50

Wavy contour (a) of the junction of the ganoblasts (c) and odontoblasts (b).
d. stellate reticulum. e. stratum intermedium.

poorly calcified than the surrounding enamel. The causes which lead to poor calcification of certain enamel rods at the dento-enamel junction are unknown. It may be supposed that during calcification, pressure from the expansion and contraction of the tissues is

an injury and results in poor calcification, as it occurs in lamellae. In the explanation of this process it may be important to know that the surface of the dentin is not a level plane but is a scallop-like surface,

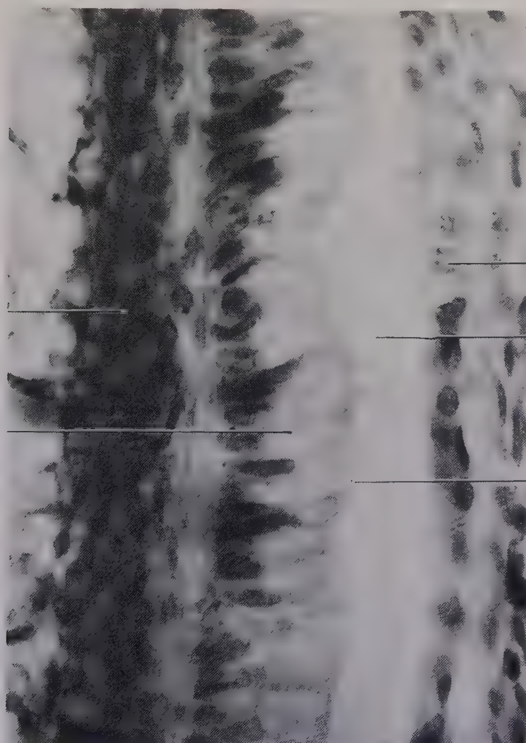


Fig. 51
After dentin (b) is built the outer surface is scallop-like (c) on which the ganoblasts (d) lie.
a. odontoblast. e. stratum intermedium.

and also that the dentin is not as hard as the enamel with which it comes in contact. It is also possible that the poor calcification of the enamel at the dentinal junction is due to the process of calcification of the peripheral layer of dentin, as will be shown later.

Dento-enamel junction

The scallop-like junction between enamel and dentin is shown in Fig. 48. The manner in which the irregular dento-enamel junction originates still is under active discussion. Since it is well known that the dentin is formed before the enamel, most investigators suppose

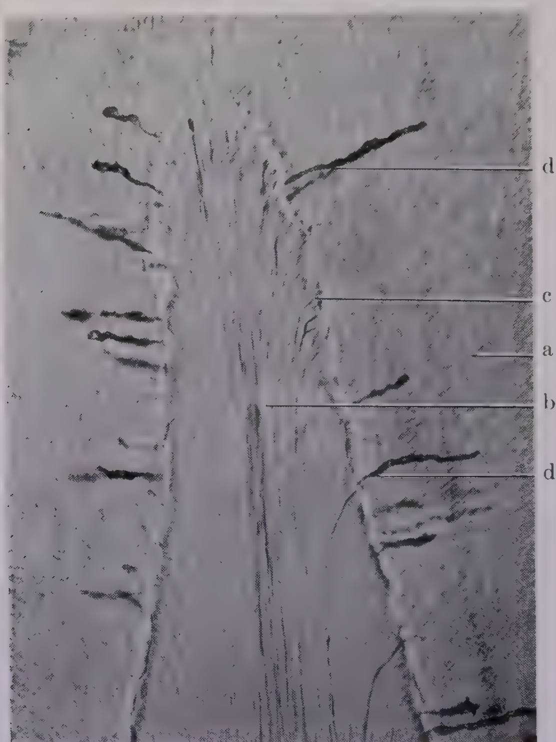


Fig. 52
Enamel spindles (d) running from the dento-enamel junction (c) into enamel (a). b. dentin.

that the ganoblasts resorb the surface of the dentin before the enamel begins to form. It is not the intention to repeat here all the arguments advanced to prove this theory of resorption but merely to call attention to facts which show that no resorption is needed to produce the scalloped form of dento-enamel junction.

We know that before dentin and enamel begin to form, the ganoblasts and the odontoblasts lie on contact with each other, Fig. 49. Most commonly the line of contact is not a straight line, or plane, as it is in Fig. 49, but is of a wavy contour much like the

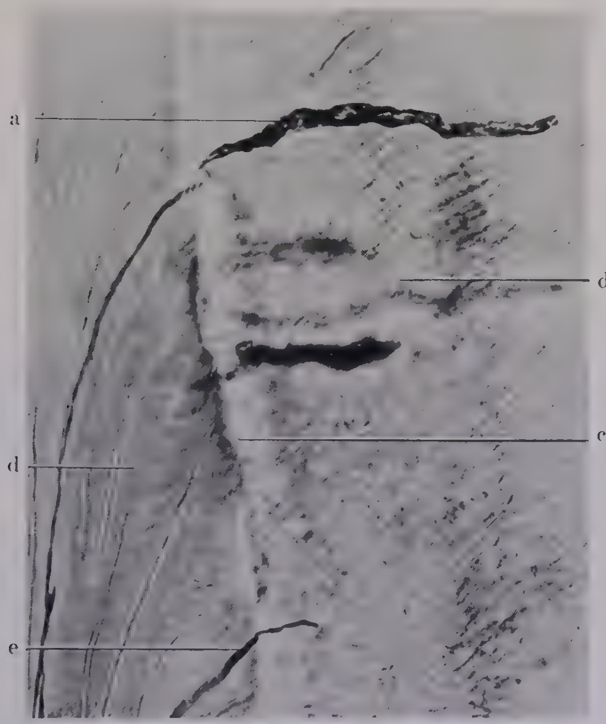


Fig. 53
Higher magnification of a spindle (a).
b. enamel. c. dento-enamel junction. d. dentin.
e. dentinal fiber penetrating the enamel.

later dento-enamel junction. This is illustrated in Fig. 50. It is possible that this scallop-like line is more sharply defined after the hard tissues, the dentin, and enamel are formed. The dentin is built before the enamel is laid down. There is a stage in development in which ganoblasts lie on the surface of the dentin as shown in Fig. 51. The outer surface of the dentin

shows *the scallop-like line*, which *is predetermined by the contact of the ganoblasts and odontoblasts before the dentin has formed.* The contact of ganoblasts with the scallop-like surface is not proof of resorption.

Enamel Spindles

The enamel spindles shown in Fig. 52 *are structures projecting from the dento-enamel junction into the enamel.* They are found mostly in the cusps, less frequent at other places of the teeth at the dento-enamel junction. Higher magnification shows these spindles in connection with dentinal tubules. (Fig. 53.) The latest investigators on this subject conclude that these spindles are composed of dentinal substance. *W. Meyer* has shown dentinal tubuli in the spindles. Some authors state that during resorption of the dentin by the ganoblasts some parts of the dentin remain unresorbed, and these areas later compose the spindles. According to these authors, the *dentinal fibers, which often may be seen in the enamel*, are also remainders of this resorption. The spindles always cross the enamel rods at an angle and are frequently inclined obliquely toward the apex of the tooth.

Dentinal fibers in the enamel

However, the presence of spindles and dentinal fibers do not necessarily prove that the ganoblasts resorb the dentin. In early development, before the enamel is built, *Lams* states that fibers and spindle-shaped processes from the odontoblasts reach between the ganoblasts to the stratum intermedium and to the stellate reticulum. It is possible that these fibers and spindle-shaped processes become embedded in the enamel as dentinal fibers and spindles. Therefore the existence of the spindles does not make it necessary to suppose that the ganoblasts resorb the dentin.

It should be emphasized (Fig. 48) that most of the branches of the dentinal fibers are just on the dento-enamel junction, and it appears as if the fibers run to the crests of the scallops. These observations together with the fact that nowhere do epithelial cells, such as ganoblasts, possess the power of resorption, furnish proof against the theory of resorption of the dentin.

CHAPTER II

PULP AND DENTIN

The dentin is a product of the connective tissue cells of the dental pulp. The pulp as a whole is a young embryonic tissue, characterized by stellate cells which are connected with each other by their protoplasmic processes. (Fig. 54.) There are no spaces between *Pulp*

FIG. 54
Pulp.

a. dentin.
b. uncalcified newly built dentin (dentinoid).
c. odontoblasts.
d. nerves in the pulp.

the cells and fibers of the pulp, and the cells and fibers of the pulp are not arranged in bundles as they are in ordinary connective tissue. Blood vessels, lymphatics, and nerves are embedded in the pulp in great abundance. It was long believed that the pulp did not contain lymph vessels. The investigations of *Schweitzer*, *Noyes and Dewey*, have shown that they are undoubtedly present. Fine capillaries may be ob-

served between the odontoblasts in close proximity to the dentin. The capillaries among the odontoblasts form a rich network which furnish a good blood supply to the cells building the dentin. The nerve fibers can

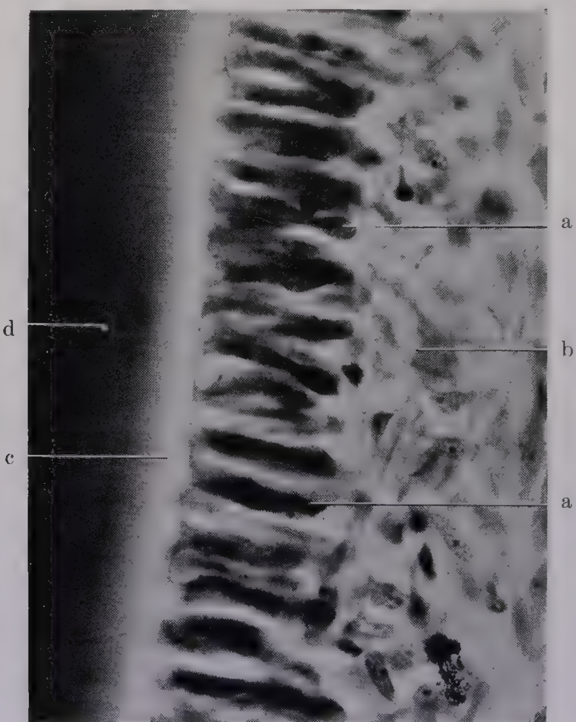


Fig. 55
Odontoblasts (a).
b. pulp tissue. c. uncalcified dentin. d. dentin.

be traced not only to the dentin, but into the dentin itself, as has been shown by *Mummery*, *Morgernstern*, and recently by *Adrion*, and *Toyoda-Dieck*. The odontoblasts are elongated cells on the outer surface of the pulp. These cells are specialized connective tissue cells. Fig. 55.

Dentin matrix

The gross structure of the dentin is that of calcified cementing substance in which collagenous fibers—(the gelatin yielding fibers) and the prosoplasmic fibers from the odontoblasts are embedded. The dentin is much like bone in its structure as well as in its origin. In general, the difference between the two is; first that the collagenous fibers in the dentin are not arranged in lamellae as they are in bone; and second, in bone the

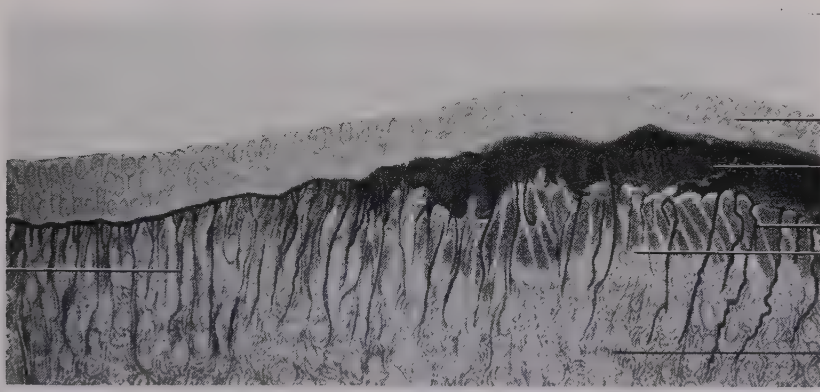


Fig. 56
First layer of dentin (b) built by the Korff's fibers (c).
a. enamel epithelium. d. odontoblasts. e. pulp tissue.
(This figure is a drawing reproduced from the work of V. v. Ebner, Vienna, 1906.)

cells are embedded in the matrix and have many fine short branches running in every direction, in the dentin the odontoblasts are not embedded in the ground substance and have only one long branch running into the dentin. These branches of the odontoblasts are known as *Tomes's* fibers (dentinal fibrils). Until recently the mode of development of the dentin has not been clear. The most reasonable description seems to be that of *V. v. Ebner*. He states that the matrix of the dentin is built from the odontoblasts in such a manner that the protoplasm of the odontoblasts becomes transformed into a collagen-like substance called

predentin. Later, in this structureless substance collagenuous fibers develop which run parallel to the surface of the pulp.

Korff's fibers *K. v. Korff* states that the odontoblasts do not build the dentin—that the dentin is formed by collagenous

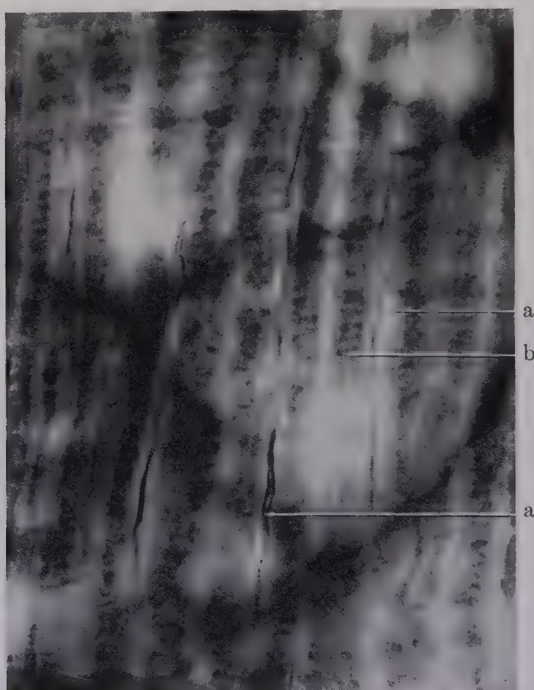


Fig. 57
Collagenous fibers (b) in the matrix of the dentin.
a. Tomes fibers.

fibers extending from the pulp. The odontoblasts according to his view build the fibers of *Tomes* only, and so form spaces in the matrix of the dentin. These spaces are for the purpose of making possible the circulation. *Ebner* states that the *Korff* fibers are produced by the odontoblasts and also by some of the

cells of the pulp. These fibers are of the same substance as the predentin. *Ebner* states that the *Korff* fibers are found only in the early formation of the den-

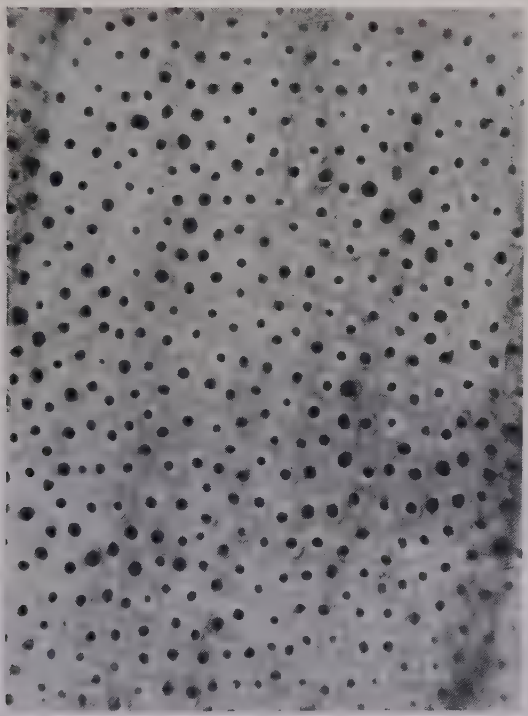


Fig. 58
Dentin.
The spaces in the matrix are the dentinal tubuli, the dark dots the cross sections of Tomes fibers. The dark lines lining the tubules are the Neumann's sheath.

tin and disappear after the dentin becomes wider than forty-eighty micra. The *Korff* fibers are to be seen in Fig. 56.

Recently *Weidenreich* investigated the development and structure of the dentin and came to the conclusion that both *Ebner* and *Korff* were right, and that there are two kinds of dentin. The peripheric zone of the

dentin which *Weidenreich* calls "*Mantel dentin*" (*cover dentin*) is developed as *Korff* describes the development of the dentin. It is built from connective tissue

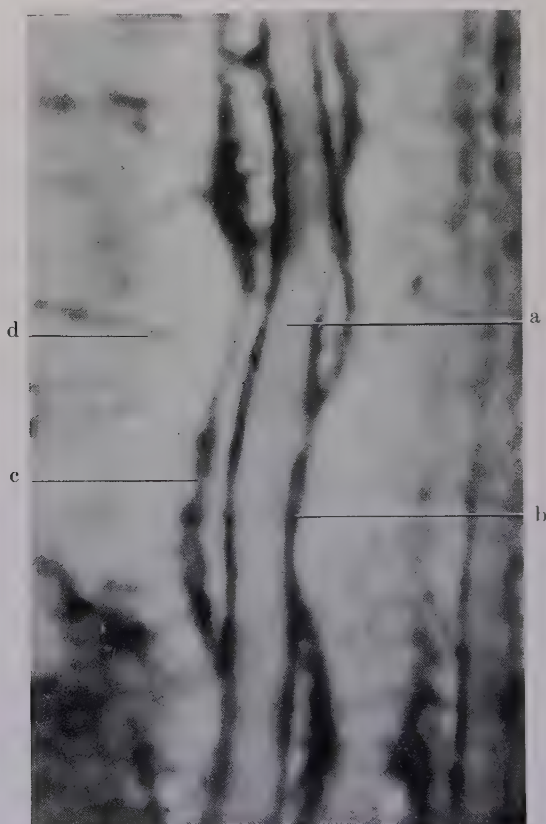


Fig. 59
Tomes fiber (a) in a dentinal tubule. The fiber stretched by shrinkage, lies at b close to the tubule wall; at c a space exists between wall and fiber.

fibers of the pulp. In this part of the dentin matrix the fibers are rougher than they are in the other part of the dentin, which *Weidenreich* calls "*circumpulpar*

dentin." This part of the dentin is formed as *Ebner* has stated, and in this portion the embedded fibers are much finer. This circumpulpar dentin forms the

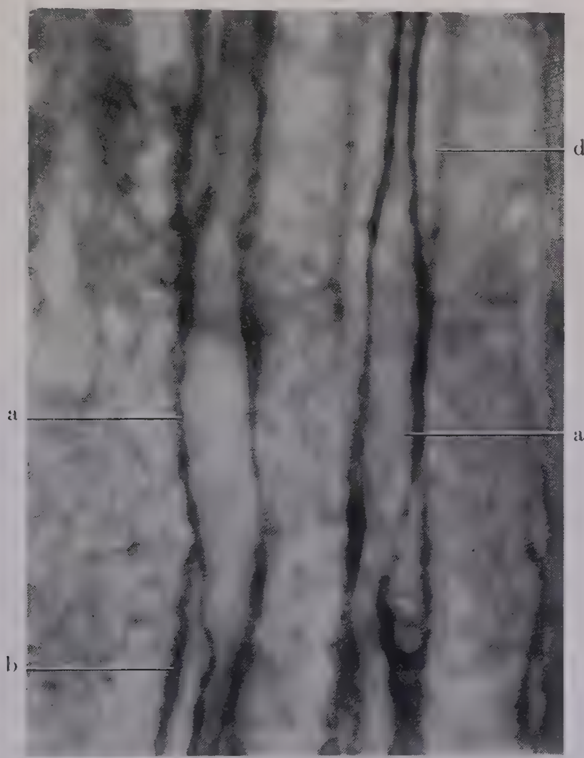


Fig. 60
Unshrunken fibers fill the entire tubule (a); shrunken fibers leave a space (b) between tubule and fiber.

larger part of the dentin, the cover dentin constituting only a thin layer on the outer surface. The collagenous fibrils described by *Ebner* run parallel to the surface of the dentin and at right angles to the *Tomes* fibers shown in Fig. 57. *To summarize, the matrix of the*

dentin consists of fine collagenous fibers embedded in a calcified medium (cementing substance).

Tomes fibers

In the matrix of the dentin there are also other fibers than those just described. These fibers may be traced

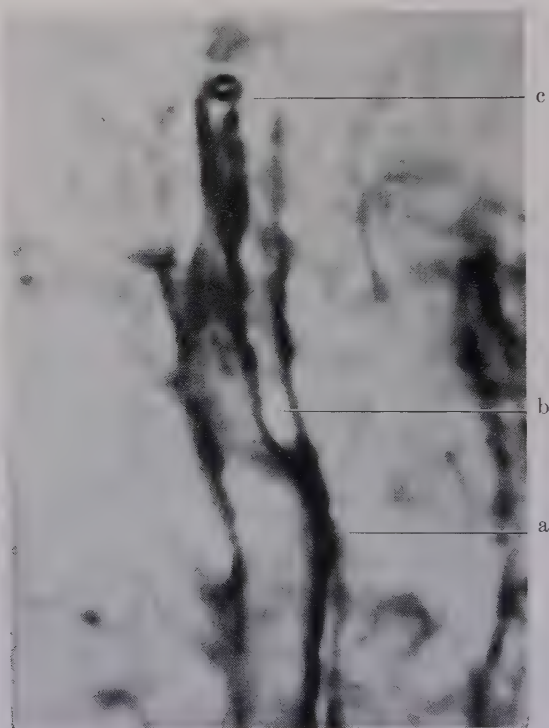


FIG. 61
Cross section of dentinal fiber showing pipe-like structure (c).
a. no shrinkage—no space. b. shrinkage—space.

from each odontoblast to the surface of the dentin; they are known as *Tomes fibers and are protoplasmic processes of the odontoblasts*. The structure of the *Tomes*

Dentinal tubules

fibers and of the so-called *dentinal tubules*, i.e. *the spaces in which the fibers run* are matters about which con-

siderable difference of opinion exists. I shall not enter into a discussion of the various arguments but will merely offer the conclusions.

A decalcified cross section of dentin is shown in Fig.

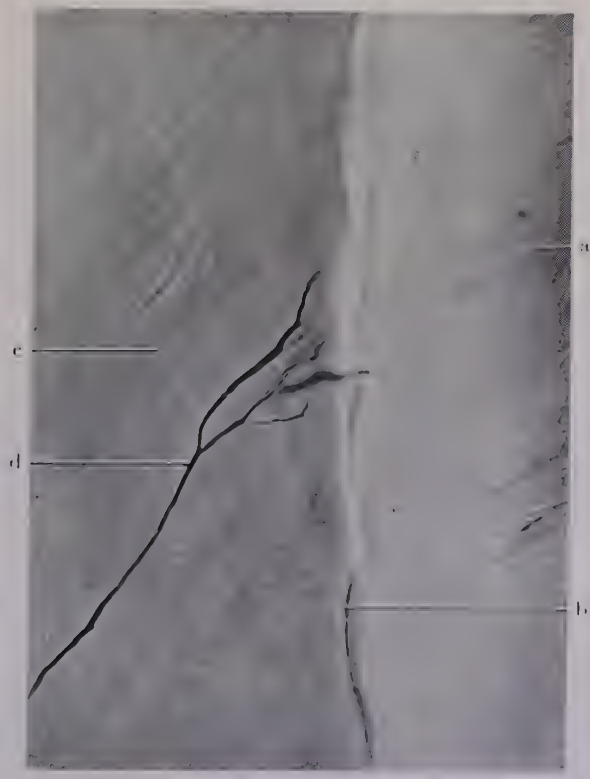


Fig. 62
Branching of Tomes fibers (d) at the dento-enamel junction (b).
a. enamel. c. dentin.

58. We observe spaces in the matrix of the dentin surrounded by dark lines, and centrally placed we see dark dots. These dots are cross sections of *Tomes* fibers, processes of the odontoblasts. The dark lines

Neumann's sheath

which surround the spaces are known as *Neumann's* sheath; a sheath which is described as being more resistant to chemical action than the rest of the dentin. In consequence of recent investigations considerable doubt arose as to whether *Neumann's* sheath exists as a real structure. It is a fact that in stained sections

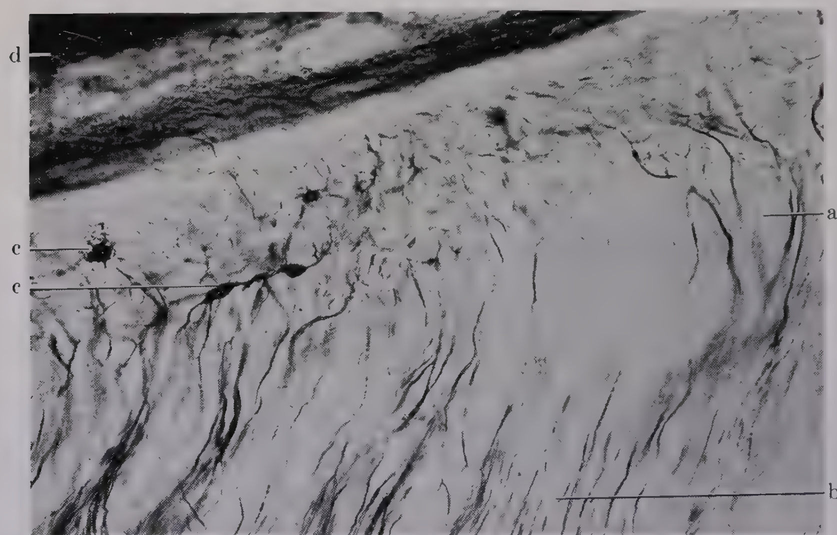


Fig. 63

Secondary dentin, with irregularly running dentinal fibers (a) and enclosed cell (c).
b. normal dentin. d. pulp.

of the dentin the walls of the tubules stain darker than the rest of the dentinal matrix. As *Ebner* states, this sheath is a continuation of the most recently formed predentin, and this structure is as resistant to chemicals as the sheath itself.

The other point which is discussed is the origin of the space between *Neumann's* sheath and *Tomes* fibers, whether this space is an artefact or exists in life. In Fig. 59[1] a *Tomes* fiber is shown in a dentinal tubule.

[1]Figures 59, 60, and 61 have been furnished by *W. Meyer*.

The dentinal tubule is slightly wavy and the *Tomes* fiber is straight. This dissimilarity in the course is due to the shortening of the fiber resulting from shrinkage. The fiber touches the convex walls of the tubule.

Fig. 64
Secondary dentin (a) built without odontoblasts, by calcification of pulp fibers (b).
c. dentin. d. pulp.

Opposite the wall which the fiber comes in contact with, a space can be seen. This is the space around which the discussion has centered. The next Fig. 60, shows that if the fibers do not shrink they fill the entire tubule. In the middle of the picture we observe

fibers that have not shrunk but have only contracted at the ends. So it is quite clear that the space between *Tomes* fibers and the walls of the dentinal tubules in our specimens is due to shrinkage and does not exist

FIG. 65
Transparent dentin (d) opposite an enamel lamella (e).
a. enamel. b. dento-enamel junction. c. dentin.

in vivo (*L. Fleischmann, W. Meyer*). In Fig. 61 it may be seen that the *Tomes* fibers are not solid compact fibers but are really tubules themselves. In other words *the Tomes fibers are pipe-like structures running through the dentinal tubule.* They are tubules within tubules. As *Ebner* states, the dentinal tubules are

about 1.3-2.2 micra wide. They are narrower toward the outer surface.

The *Tomes* fibers give off many short branches along their courses, but most of the branches are found at

Fig. 66
High magnification of transparent dentin.
a. normal dentin.
b transparent dentin, the dentinal tubules filled with calcified substance.

the dento-enamel junction as shown in Fig. 62 and 48. The course of the dentinal tubules is a slightly S-shaped line and not a straight line from the outer surface to the pulp. The innermost layer of the dentin is norm-

ally uncalcified, because the dentin is laid down first as an uncalcified matrix in which later the calcium salts are deposited or precipitated. The calcium salts are deposited from the pulp, so the most recently

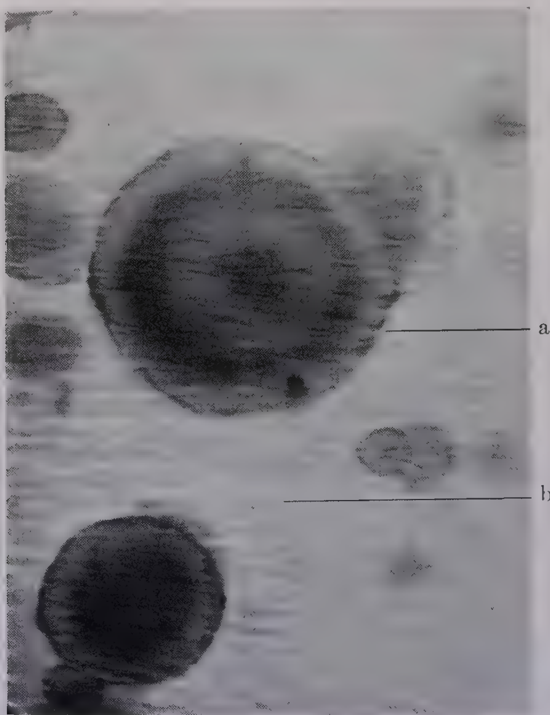


Fig. 67
Calcium globuli (a) in the uncalcified matrix of the dentin (b).

formed dentin is always uncalcified. The same is true of bone and cementum.

Some structures found in almost every tooth must be mentioned here with the remark that they do not quite belong to the normal structures but lie on the borderline between the normal and the pathological.

Their frequent presence furnishes an excuse to describe them here. One of the structures referred to is the so-called *secondary dentin.* This secondary dentin is a product of the odontoblasts caused by an irritation on the outside of the tooth, or inflammation in the

Secondary dentin

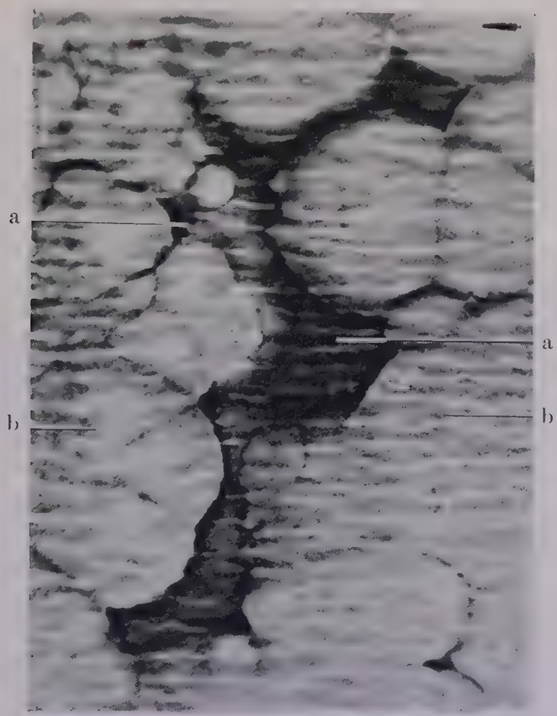


Fig. 68
Interglobular spaces (a) in the dentin (b).

pulp. The odontoblasts react to the irritation and form dentin more rapidly than they do without irritation. The result of this rapid production of dentin is that the dentinal tubules in the new secondary dentinal area are not as regular as those in the primary dentin. The tubules also run in different directions

in the former than they do in the latter structure. It is characteristic that there are fewer tubules in the secondary dentin than in the primary. This peculiar difference in structure is probably due to the fact that

Fig. 69
Three layers of interglobular dentin (b) in a molar.
a. enamel.

some of the odontoblasts are resting at the time the irritation occurs, while their neighboring cells are active. Thus while active cells are continuing their function, the resting cells remain embedded in the matrix or degenerate and disappear. Therefore we see pulp cells embedded in the secondary dentin and consequently

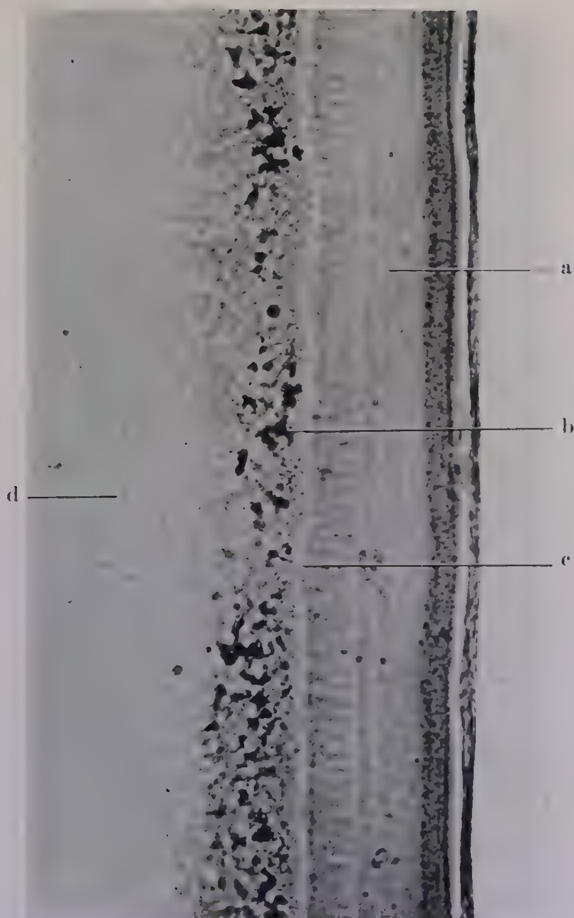


Fig. 70
Tomes granular layer (b).
a. cementum.
c. dento-cemental junction.
d. dentin.

less *Tomes* fibers than in the primary dentin. Secondary dentin is shown in Fig. 63 originating from a ground section of an extensively abraded tooth of an

old man. Frequently we see deposited another type of secondary dentin.

This dentin has no *Tomes* fibers because it is not built by odontoblasts but by fibers of the pulp, Fig. 64.

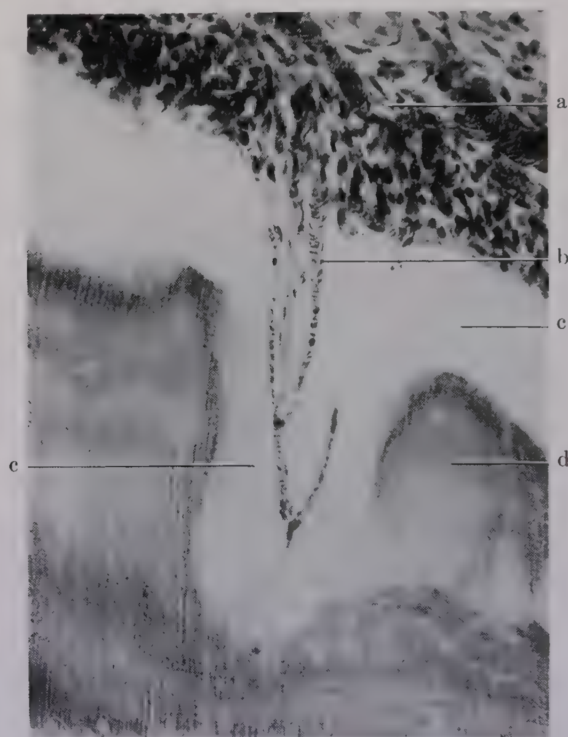


Fig. 71
Calcification of dentin (d) is poor (c) around enclosed blood vessels (b) and near to the pulp (a).

This process seems to be similar to that of first development of the dentin in which the *Korff* fibers play the main role. This type of secondary dentin accompanies mostly degenerative and inflammatory processes of the pulp.

Transparent dentin

The transparent dentin should also be mentioned.

The calcification of *Tomes* fibers is characteristic of this structure. Areas in the dentin are homogeneously calcified and therefore transparent. This calcification has been believed to be due to a vital response of the *Tomes* fibers to irritation such as caries. Frequently we see transparent dentin opposite lamellae as shown in Fig. 65 originating from a grinding. This transparent area is the result of an irritation transmitted by the lamella from the surface of the tooth of the dentin. It has been stated recently by *Siegmund and Weber* that the transparent dentin is not the result of a vital reaction of the pulp but is due to a fatty degeneration of the *Tomes* fibers caused by the irritation. After the *Tomes* fibers degenerate, calcium salts are deposited in them, and in this way the transparent dentin is developed. Fig. 66 shows the difference between the transparent and the normal dentin more clearly.

Interglobular spaces

In the calcification of the dentin *the calcium salts are* probably *deposited* by the odontoblasts *in the form of globules.* (Fig. 67.) If the globules are very small and numerous and close to each other, they present a homogeneous appearance. If the globules are large and not so numerous, spaces of uncalcified matrix remain between them—the interglobular spaces. The inter-globular spaces are not real spaces, but are uncalcified dentin matrix limited by calcified globules. Therefore the borders of these interglobular spaces are irregular as shown in Fig. 68. It is evident that the dentinal tubules, as well as *Tomes* fibers, should run through these "spaces". Interglobular dentin may be seen in any part of the dentin but is most frequently seen in the enamel covered portion of the tooth. Since this dentin is a sign of poor calcification, it is also an indication of disturbance in the calcium metabolism during development.

Sometimes three and even more layers of interglobular spaces appear, Fig. 67. It must be noted that

in the enamel covered portion of the dentine the interglobular spaces are not quite at the dento-enamel junction, but lie deeper in the dentin.

Granular layer of Tomes

The granular layer of Tomes is nothing else than a layer of very small interglobular spaces on the surface of the dentin, in the root portion of the tooth covered

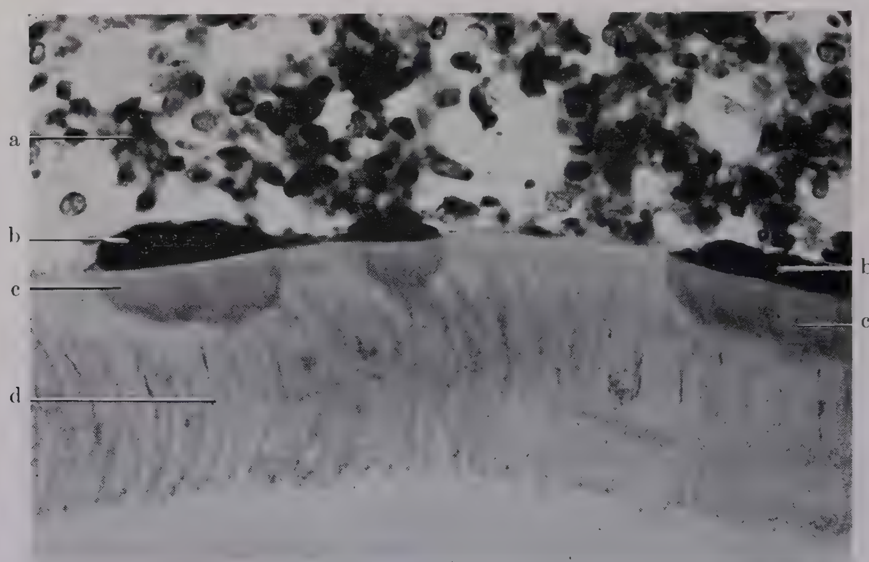


Fig. 72
Calcification of dentin (d) is good (c) only at places lying opposite enamel droplets (b). Where no enamel is built no calcification occurs.
a. destroyed enamel epithelium.

by cementum. Fig. 70 shows this formation. We observe the dentinal tubules ending in this layer of small interglobular spaces. Many investigators state that the granular layer is due to a widening of the ends of the *Tomes* fibers. A difference between the *Tomes* granular layer and the interglobular spaces, aside from the fact that the latter are larger, is that the former

lie quite near to the cementum in the dentin while the latter lie deeper in the dentin.

Calcification and Metabolism

To understand the origin of the *Tomes* granular layer some general statements regarding calcification are necessary. It is a well-known fact that calcification does not occur readily where the blood supply is

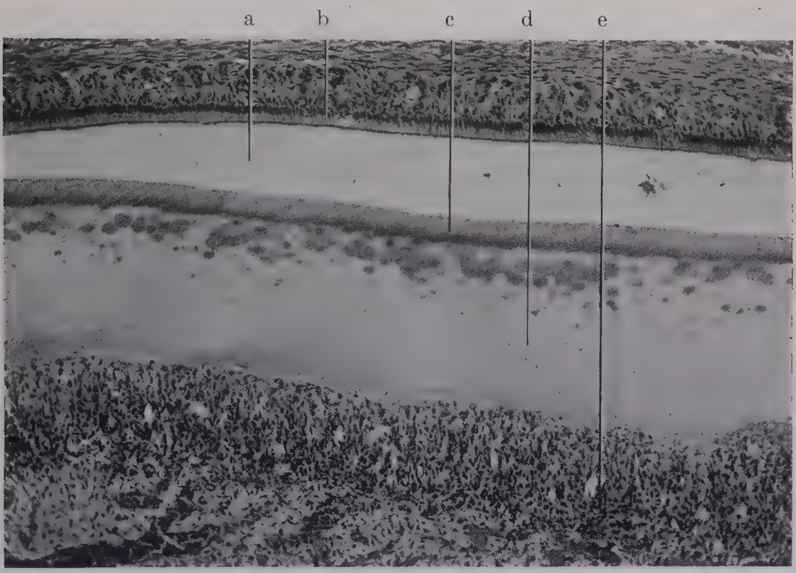


FIG. 73
Calcification of dentin (d) of a rat on a deficient diet occurred only under the enamel in the outer layer of the dentin (c).
a. enamel. b. enamel epithelium. e. pulp.

abundant. *Erdheim* has shown in his work on rickets that blood vessels often are enclosed in the dentin in this disease. Such a blood vessel may be observed in the Figure 71. Around the blood capillary, the dentin is lightly stained indicating poor calcification, but a little further away from the blood vessel calcification has taken place. In the vicinity of the blood vessel the metabolism is so active that calcification cannot take place. Wherever there is a poor blood supply the

vitality of the tissue is low and as a result deposition of calcium salts occurs. In parathyroidectomized rats the enamel is frequently very poorly formed and is not laid down in a continuous layer but in irregular droplets. In such rats the dentin is frequently wholly uncalcified. We observe a case shown in Fig. 72 with only a few enamel droplets deposited on the surface of the dentin. We see opposite the enamel droplets the dentin stained darker (Haemotoxylin-Eosin) which signifies a good calcification. Other places in the dentin without enamel covering are lightly stained and indicate poor calcification. This statement that dentin is better calcified when it is covered with enamel may be proven also in other ways. A photograph of a tooth of a rat fed with a poor diet is shown in Fig. 73. Here we observe the whole dentin poorly calcified and lightly stained, only one layer, beneath the enamel, being homogeneously calcified. We can go a step further and state that *the calcification of the outer surface of the dentin depends upon the condition of the tissues found on its surface.* It is not only true of the enamel-covered portion of the tooth that the calcification of its peripheral portion depends on the presence and quality of the overlying tissue, but it is also true of the cementum-covered portion of the tooth. Fig. 74 shows the lingual surface of a tooth of a rat fed on a poor diet. A part of the cementum is uncalcified, and the dentin lying underneath this, is also uncalcified. Calcified dentin is to be seen only opposite the calcified cementum (darkly stained).

The general statement can be made that *the calcification of the outer surface of the dentin of the entire tooth depends on the presence of calcified enamel or cementum.* It cannot be said that the calcium salts come from the enamel or cementum, but it is probable that the presence of this calcified tissue on the surface makes the calcification of the underlying dentin possible.

If we return to the previous statement that a poor blood supply with its associated low metabolism is necessary for good calcification, it will be clear why we find the granular layer of *Tomes* on the peripheral

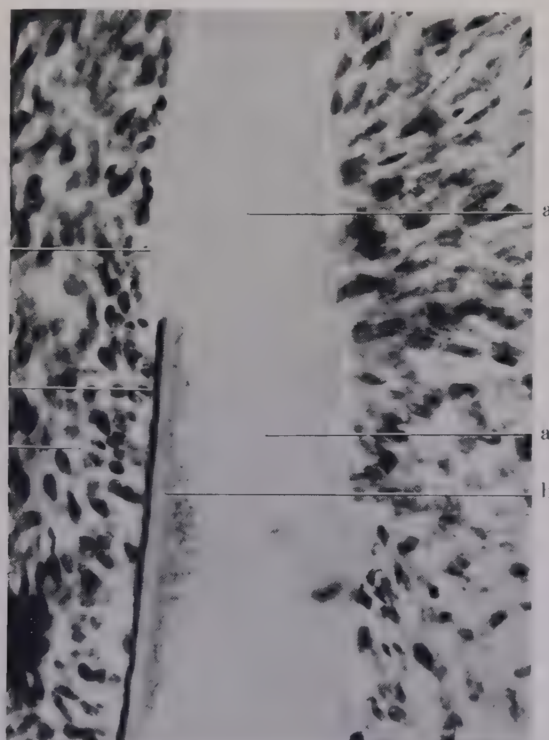


Fig. 74
Calcification of dentin (a) of rat on deficient diet occurred (b) only under calcified cementum (c). The dentin remains uncalcified wherever the cementum is uncalcified (e).
d. periodontal membrane.

surface of the dentin of the root and not underneath the enamel. Very soon after the dentin is built as an uncalcified matrix, the enamel is laid down on its surface, and so the peripheral dentin is covered at

the crown portion by a medium which has a poor blood supply. Since there are no blood vessels in the

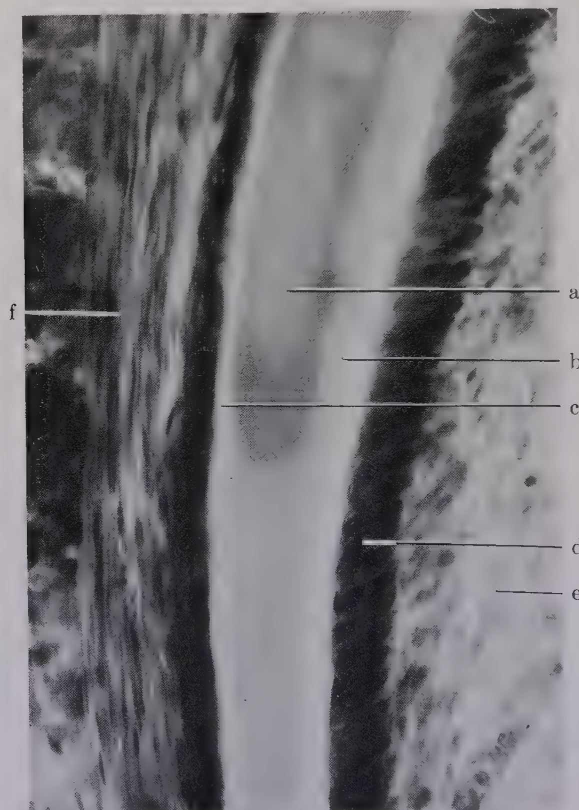


FIG. 75

The outer layer of dentin (c) remains uncalcified as the other parts of the dentin calcify (a). The inner layer (b) which is the last product of the odontoblast (d) calcifies later.
e. pulp.
f. periodontal membrane.

enamel organ, and the dentin is separated from the surrounding tissues, the metabolic activity is kept low, and this assures a good calcification.

The relationship between the dentinal surface and the surrounding tissues of the root is different. After the dentin is laid down and the continuity of *Hertwig's* epithelial sheath (described later) is broken, the outer surface of the dentin is exposed to the connective tissue, in which the metabolic activity is high. Due to this high metabolism the calcification of the peripheral dentin is retarded as shown in Fig. 75. We see here a part of a root of a developing tooth being formed. The inner layer (b) of the dentin is lightly stained and is the last uncalcified product of the odontoblasts. We observe that not only the inner but also the outer layer (c) of the dentin is poorly calcified. Both uncalcified layers are in connection with the most recently formed lower portion of the root.

This outer layer of dentin which remains uncalcified as the dentin becomes primarily calcified later forms the *Tomes* granular layer. As the tooth development proceeds, the cementum is deposited on the outer surface of the root and becomes calcified. Thus the uncalcified dentinal layer on the outer surface of dentin is separated from the highly active connective tissue. By this separation it is possible that the primarily uncalcified outer layer of the dentin becomes calcified, but the calcification of this secondarily calcified dentin layer is not as perfect as in the other part of the dentin which was previously calcified. *The Tomes granular layer is the result of a disturbance of calcification due to contact with tissue of high metabolic activity.*

CHAPTER III

CEMENTUM

The cementum is a calcified structure found on the surface of the root. It is composed of collagenous fibers connected with each other by a calcified cementing substance. The matrix of the cementum is very similar to that of bone and does not differ very much from bone morphologically. The main difference between the two is that the collagenous fibers in the bone run parallel to the surface of the bone lamellae, but in the cementum they are at right angles to the surface. The function of the cementum is to attach the tooth through the embedded periodontal membrane fibers with the alveolar bone.

Matrix

Function

The deposition of the cementum begins previous to the eruption of the tooth after the greater part of the root is formed.

Before the cementum is deposited on the surface of the dentin, the dentin lies only in contact with the surrounding connective tissue without being in organic connection with it. The dentin is built by the odontoblasts of the pulp, and if we may use the biologic expression of *Gottlieb* regard it as a calcified structure implanted by the odonotoblasts in the surrounding tissue. This "implanted" dentin becomes united with the surrounding tissue through the medium of the cementum.

The tissue surrounding the toothgerm is the periodontal membrane. It is also known as tooth-sack. "Tooth sack" is an erroneous term which leads to the misconception that it is an organ. This is decidedly not the case. The tissue surrounding the toothgerm is merely compressed periodontal membrane. The compression results from the growth of the toothgerm. It is probably this compressed appearance that has lead to the belief that this "tooth sack" is a specialized organ.

Primary cementum

There are two kinds of cementum, primary and secondary. The primary cementum is a calcified matrix

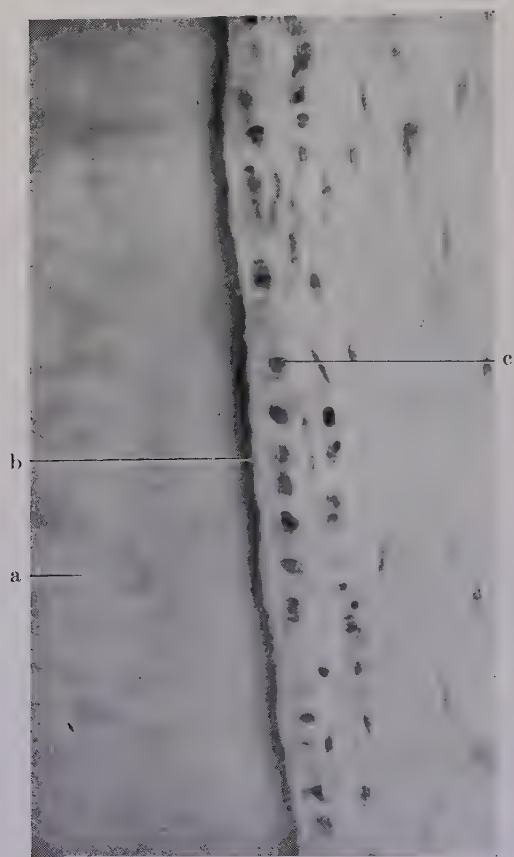


Fig. 76
First deposition of cementum (b) by cementoblasts (c). a. dentin.

built by the cementoblasts. The characteristic of *the primary cementum* is that it *does not contain cells embedded* in the matrix. In Fig. 76 we see the cementoblasts beginning the deposition of the cementum.

Fig. 77 shows a specimen prepared by the silver-impregnation method. The embedded periodontal

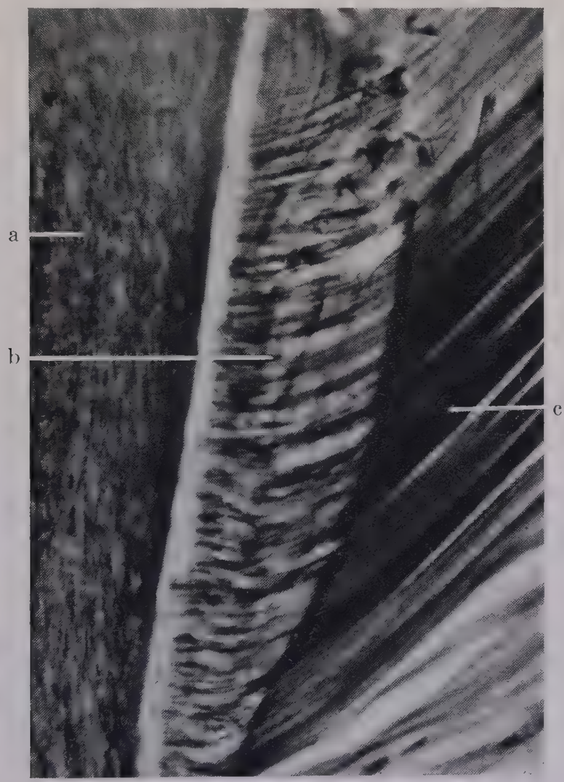


Fig. 77
Primary cementum (b) with embedded Sharpey's fibers.
a. dentin. c. fibers of periodontal membrane.

membrane fibers in the cementum can be traced very clearly. These are the so-called *Sharpey* fibers.

The primary cementum covers the entire root only in a limited number of cases. In the majority of cases the apical third of the root is free from primary cementum and is covered by secondary cementum.

Secondary cementum

Sometimes the secondary cementum is laid down on the surface of the primary. The secondary cementum is a bone-like structure. Its matrix is like that of bone and primary cementum. *The characteristic of this substance is that it has cementoblasts enclosed in its matrix. The so-called cement corpuscles* are similar to the bone corpuscles but vary from them in size and shape, and are more irregular.

Fig. 78 is an illustration of primary cementum from the upper third of a root. On the periodontal membrane side the cementum is uncalcified. The cementum is laid down as a matrix which later becomes calcified. The uncalcified outer layer is evidence of new deposition of cementum.

Fig. 79 originates from the apical third of the same specimen. This cementum is of the secondary type. It is deposited directly on the dentin. The cement corpuscles embedded in the calcified matrix vary in size. The outer uncalcified layer indicates new deposition. By this new building cementoblasts are continuously enclosed as illustrated in this picture. Generally the secondary cementum is of greater thickness than the primary. In comparison with the last two illustrations which are of the same magnification this is apparent. Connective tissue fibers are embedded also in this cementum just as they are in the primary cementum as shown in Fig. 80 by silver impregnation. The causes which lead in one case to the deposition of primary cementum on the larger portion of the tooth, and in the other, to the deposition of secondary cementum at the apex only must be left to future investigation.

Both kinds of cementum are laid down in lamellae —most of which run parallel to the surface of the root. These lamellae mark the different periods of growth in a manner analogous to the formation of rings in the growth of trees. These lamellae, however, have no reference to the age of the individual,

although there are more lamellae in old age. The cementum is the most important part of the developed tooth. A cavity in the tooth may be filled, an entire crown may be replaced, and a tooth may be retained in the mouth without a pulp, but no tooth remains fixed in the mouth without cementum. The most

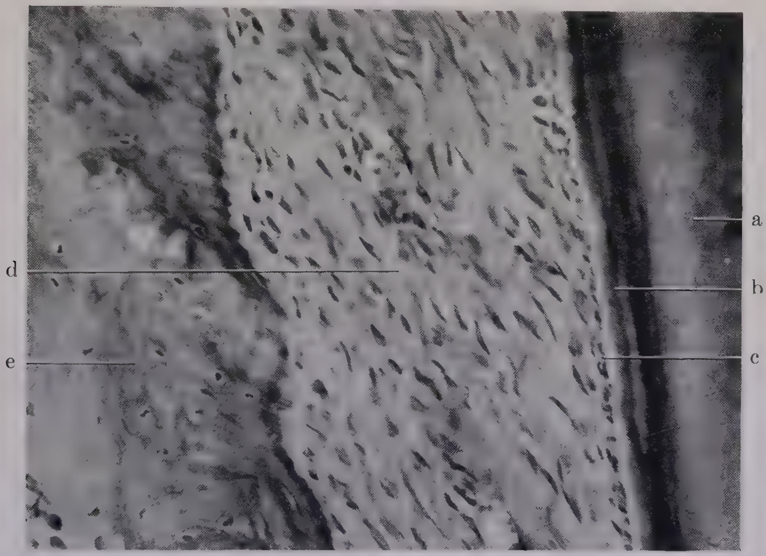


FIG. 78
Primary cementum (b).

a. dentin.
c. uncalcified, newly built cementum.
d. periodontal membrane.
e. alveolar bone.

important part of the tooth as far as the individual is concerned is the root which is attached to the alveolar bone through the medium of the cementum.

Between the cementum and dentin there is frequently found a layer not resembling either in structure. This can be seen in the majority of stained decalcified sections illustrated in Fig. 81. We call this layer the "*intermediate cement layer*" (*Bencze*). There is no sharp line of demarcation between the

Intermediate cement layer

different layers. The cementum, in this case (Fig. 81) does not contain any cells; it is a primary cementum. The intermediate cement layer shows large irregular cells enclosed in a fibrous calcified matrix. This layer must not be confused with the granular

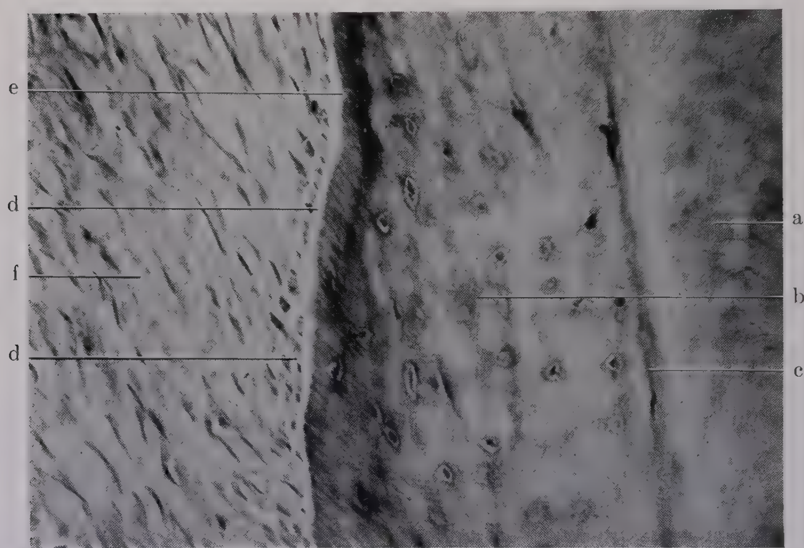


FIG. 79
Secondary cementum (b).
a. dentin.
c. dento-cemental junction.
d. uncalcified, newly built cementum.
e. enclosed cementoblast.
f. periodontal membrane.

layer of *Tomes* which is located on the periphery of the dentin. If we observe the development of this intermediate layer we find it developing on tooth-germs in which cementum is not yet formed. Such a case is shown in Fig. 82. We see the connective tissue cells of the periodontal membrane enclosed in a fibrous matrix probably built by these cells. After the development proceeds, the normal cementum is deposited on the surface of this layer. This intermediate

structure is not to be found on the whole root, but mostly on the apical two-thirds of the tooth. Sometimes it is a continuous layer, sometimes it is fragmentary. The cells enclosed in this matrix are larger than the cells of the secondary cementum or bone.

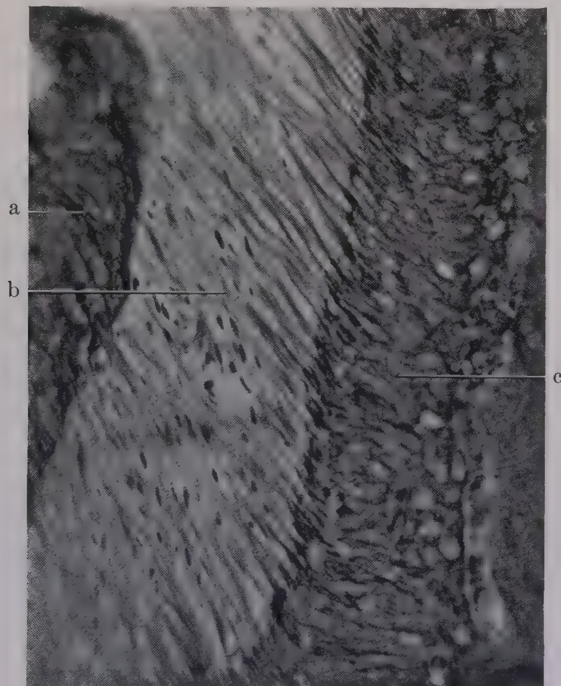


Fig. 80
Sharpey fibers embedded in secondary cementum (c).
a. alveolar bone. b. periodontal membrane.

They are also more irregular in shape. It may be found under either primary or secondary cementum.

It seems to be of practical importance whether there is a fibrous or tubulous connection between dentin and cementum or not. Both opinions have their ad-

vocates. However, no convincing histologic proof has been furnished to substantiate either view.

The building of cementum is a continuous process. (*G. V. Black*). New layers of cementum are laid down successively, and in this way the connective tissue fibers of the periodontal membrane become more and more firmly embedded. *The retention of the tooth,* as *Gottlieb* has pointed out, *is dependent upon this continuous building of cementum.*

Cementum and alveolar bone

The alveolar bone develops subsequent to the deposition of cementum. The connective tissue fibers of the periodontal membrane become connected with the tooth through cementum. The tooth, while it is in the process of eruption, transmits this stimulus of eruption through the connective tissue fibers to the surface of the bone surrounding the teeth. As a result of this stimulus new bone trabeculae are laid down and form alveolar bone. This will be shown in the chapter on alveolar bone.

Resorption and Repair

It must be understood that the cementum is built by the connective tissue of the periodontal membrane and that it may also be resorbed by it. The cementum is a living tissue. It has a metabolism and, as the recent experiments of *Fish* have shown, a lymph circulation. *The cementum may be resorbed by the surrounding connective tissue and may be reformed if the cause of the resorption has subsided.* In the morphological structure as previously described, there is little difference between bone and cementum, but according to the investigations of *Gottlieb*, we are convinced that there are remarkable differences in their biologic behavior. Continuous resorption and new building of bone is a physiologic process. But the resorption of cementum is not so common. We know from observations in orthodontia that during movement of the tooth the bone becomes resorbed in the direction of movement. The periodontal membrane is compressed between the bone and the cementum in the

direction of movement, and this increased pressure is exerted on the bone as well as on the cementum, but the cementum does not become resorbed. (If the

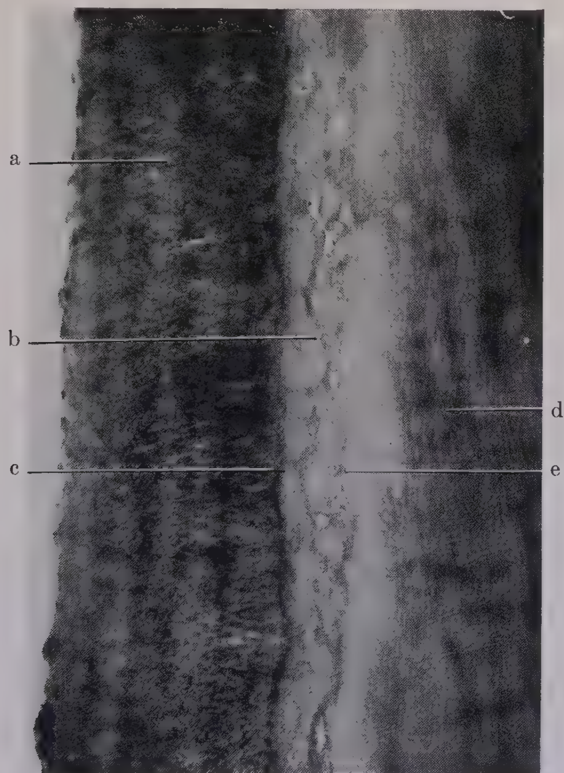


Fig. 81
Intermediate cementum layer (b) between cementum (a) and dentin (d).
c. border between cementum and intermediate layer.
e. border between dentin and intermediate layer.

force applied becomes too strong, resorption of the cementum may also take place.) Bone and cementum do not react to irritations in the same degree. *Gottlieb* claims that the resorption of cementum, dentin,

or bone depends not only upon the condition of the surrounding soft tissue; but also upon the quality of the cementum, bone, or dentin. It has been shown that the degree of calcification influences resorption:

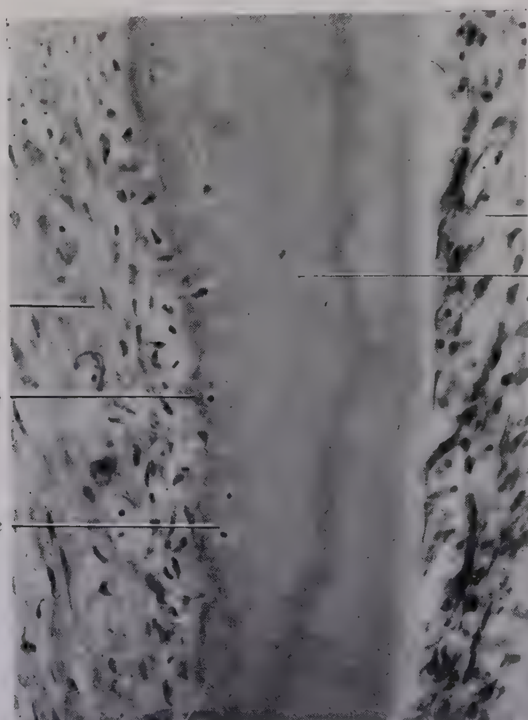


Fig. 82
Development of intermediate cementum layer. Cells (c) of periodontal membrane (d) become enclosed in a calcified matrix deposited on the surface of the dentin (b).
a. pulp.

well calcified tissue becomes resorbed more easily than newly built, poorly calcified tissue. In the specimen Fig. 83 (*Kronfeld*) is illustrated the difference in the rate of resorption of well calcified and poorly calcified tissue. The specimen is from a deciduous tooth in

the state of being resorbed. The inner layer of the dentin, the most recently developed uncalcified dentin, is not resorbed but the surrounding well calcified dentin is resorbed. We believe also that the new

FIG. 83
Resorption of a deciduous tooth. The permanent toothgerms develops in the direction of the arrow. The calcified dentin is resorbed; the uncalcified inner layer (b) resists resorption.
a. dentin. c. pulp.

deposition of cementum in a resorbed area depends not only upon the condition of the surrounding tissue but also upon the quality of the cementum, dentin, or bone.

Repair by primary cementum

Fig. 84 shows the line of an old resorption extending through the cementum into the dentin. During the

Fig. 84
Functional repair.
Resorption of cementum and dentin occurring at the line (d) is repaired by deposition of primary cementum. Alveolar bone (a) restores the normal width of the periodontal membrane (c).
b. periodontal membrane where no resorption has occurred.

time of the original resorption the connection between the periodontal membrane fibers and the tooth were severed, because of the resorption of the cementum

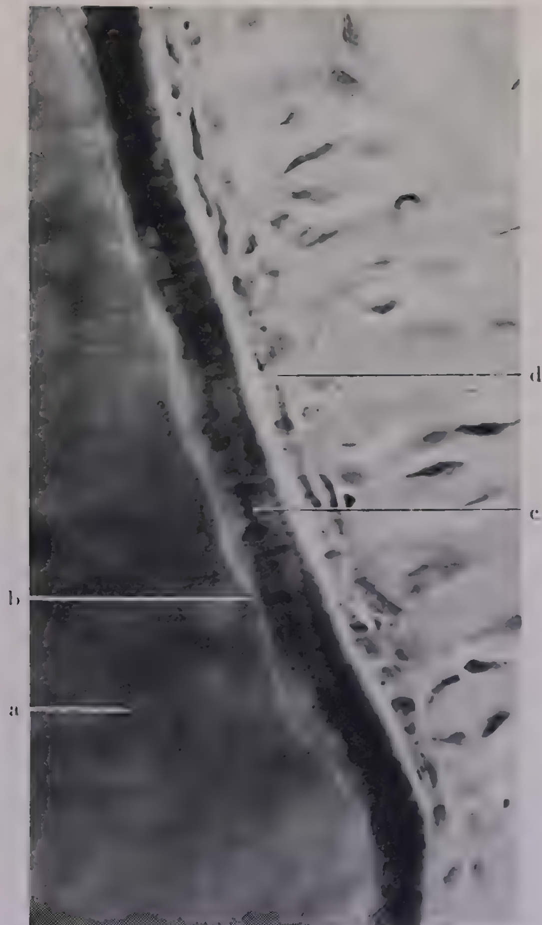


Fig. 85
Higher magnification of Fig. 84.
a. dentin. b. line of resorption.
c. repair of resorption by primary cementum.
d. uncalcified newly built cementum.

in which the fibers were embedded. After the cause of the resorption had subsided, new cementum was formed and fibers were again embedded. *The cemen-*

tum built in this case is from the primary type as shown in Fig. 85 by higher magnification.

The existence of the alveolar bone depends upon the existence of cementum. Without cementum no alveolar

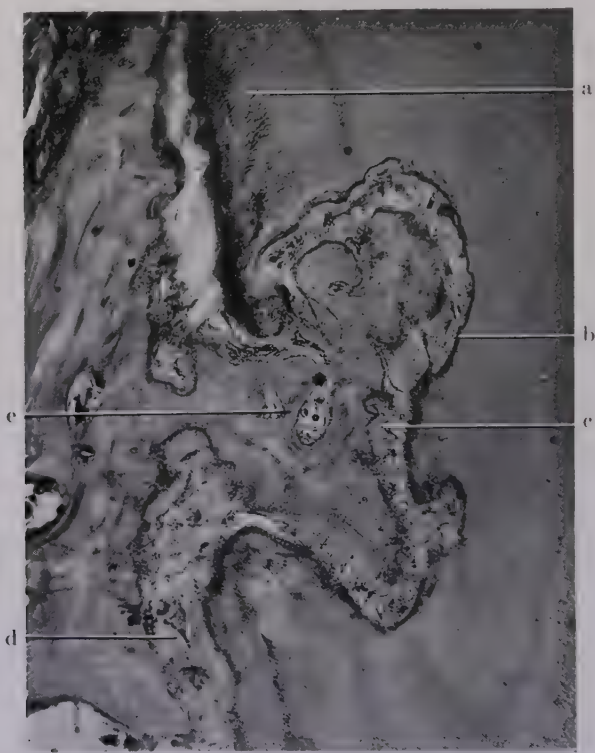


Fig. 86
Functional repair.
Resorption of root at line (b) New bone (e) fills the resorption space leaving only a normal periodontal membrane (c).
a. cementum. d. periodontal membrane where no resorption has occurred.

bone is possible! If the cementum is resorbed the alveolar bone lying opposite it also becomes resorbed. Whenever the new formation of cementum begins there

is a corresponding new building of bone. To avoid misunderstanding it must be mentioned that resorption of the alveolar bone also may occur under cer-

Fig. 87
Repair by secondary cementum (c).
a. dentin.
b. resorption at this line.
d. restored periodontal membrane.
e. new alveolar bone.
f. alveolar bone outside of resorption.
g. periodontal membrane.
h. unresorbed surface of tooth.

tain pathologic conditions without resorption of the cementum. A remarkable case showing the possibility of repair in a case of resorption is shown in Fig. 86. We can follow the resorption deep into the dentin.

After the resorption stopped, new cementum was deposited upon the resorbed surface. Through this cementum new periodontal membrane fibers became attached to the tooth. These fibers transmitted the functional stimulus to the bone, and in response to this stimulus new bone building resulted. This bone building continued up to the point where the normal thickness of the periodontal membrane was again re-

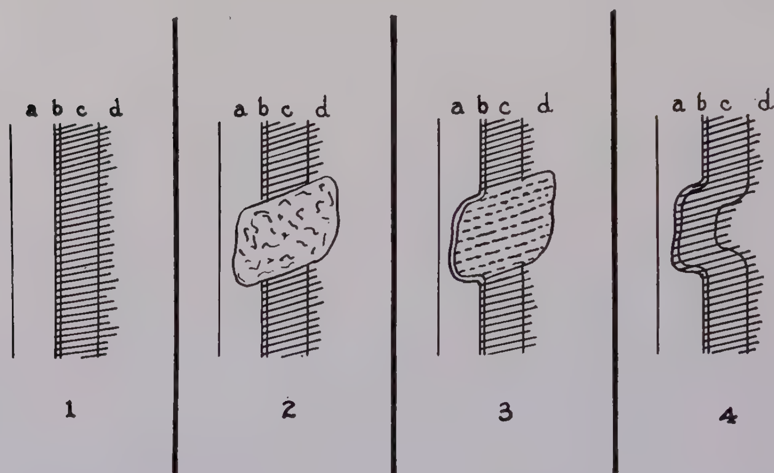


Fig. 88
Diagram showing process of functional repair. Description in text.
a. dentin.
b. cementum.
c. periodontal membrane.
d. alveolar bone.

established. It is not necessary that a resorbed area be completely restored with cementum in order to constitute a repair. *A functional repair requires the deposition of a layer of cementum, reattachment of fibers, and the re-establishment of the normal thickness of the periodontal membrane, by building of bone.*

Functional repair

Repair by secondary cementum

A repair of resorption occurs not only through the deposition of primary cementum as in the case of Fig. 84, *but in the majority of cases by deposition of secondary cementum* as illustrated in Fig. 87. The character of

the repair, as far as we know, bears no relation to the functional integrity of the tooth.

The diagram Fig. 88 is used to illustrate the process which takes place during resorption and repair. The *first* diagram shows the normal case. The periodontal membrane fibers are functionally oriented. They extend obliquely from the cementum to the bone embedded at both ends in hard substances. The *second* diagram shows the change caused by resorption which has resulted in the loss of functional orientation of the periodontal membrane fibers. The corresponding bone is resorbed as a result of the loss of the functional stimulus. The *third* diagram illustrates a stage in which new cementum has again been deposited on the surface of the dentin. Connective tissue fibers have become embedded in the cementum and have established again the functional connection between tooth and bone. New bone is formed in consequence of this stimulus. Bone deposition continues until the normal thickness of the periodontal membrane is re-established. Diagram *four* corresponds to the conditions in the photomicrograph shown in Fig. 84. However, it should be evident that the processes of resorption and repair do not always take place in the manner described. Sometimes resorptions are not repaired, but may continue until the tooth becomes completely detached and lost. At other times the entire resorbed area may be entirely rebuilt with new cementum, with no bone grown into the resorbed area. Between the cases of repair just discussed, there are many variations, possibly as many as there are individuals.

Cementum hyperplasia

Another phenomenon of the cementum is the development of cementum hyperplasia. A great number of investigators and many clinicians believe that cementum hyperplasia is pathologic. We are however, of the opinion that there is little basis for this assumption. *Cementum hyperplasia is a favorable reaction to irri-*

tation. Under irritation we understand different influences such as functional stress, inflammation, and also resorption of alveolar bone. If the alveolar bone for any reason becomes resorbed and the periodontal

Fig. 89
Spike-like cementum hyperplasia (c) due to functional stress.
a. cementum. b. dentin. d. alveolar bone.

space becomes wider, a reparation in the form of new building of cementum may take place. This favorable reaction does not always occur, but if it does, it should not be considered a pathologic process. Investigations have not yet revealed all of the causes of re-

sorption nor the causes of repair; general physical conditions may be a factor.

A cementum hyperplasia can be built either of primary or of secondary cementum. A cementum hyperplasia of primary cementum of a tooth subjected to great stress is shown in Fig. 89. The spike-like cementum hyperplasia in this case is evidence of very favorable

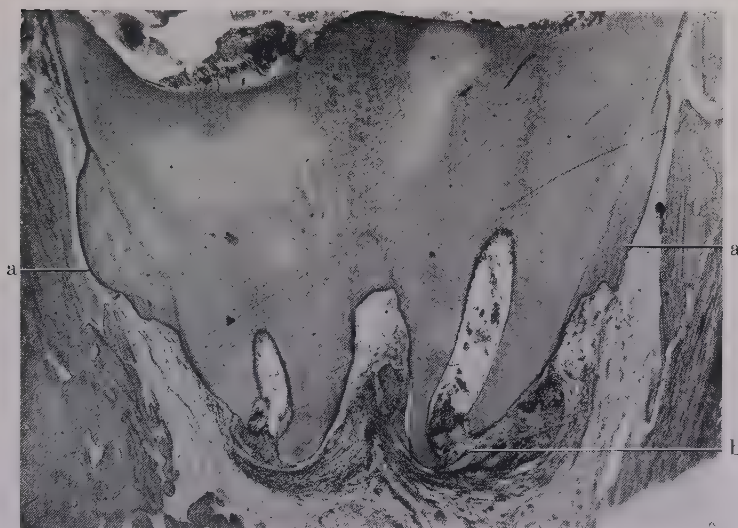


Fig. 90
Cementum hyperplasia (a) due to inflammatory irritation from granuloma (b).

tissue reaction. The cementum hyperplasia extends in the direction of the periodontal membrane fibers. This offers a good attachment for the fibers and strengthens the tooth in its socket. A cementum hyperplasia due to inflammatory irritation is shown in Fig. 90. We observe a granuloma formation at the root apices of a bicuspid. Through this inflammation not only the alveolar bone was destroyed, but a large number of the periodontal membrane fibers were also

detached from the cementum. This detachment of fibers led to a weakening of the tooth, which was compensated in this instance by a cementum hyperplasia. The cementum hyperplasia amounts to an increase in the tooth surface. This permits more fibers to become attached to the tooth, and thereby offsets the damage done to the tooth by loss of fibers through the inflammation. The deposition of cementum is a continuous process. It increases in thickness during life. If no apparent irritation intervenes, a slight thickening of the cementum of the dentition takes place. In cases where irritation does intervene, the reaction depends upon the tissue condition of the individual. *Under unfavorable conditions resorption and loosening of the teeth takes place. Under favorable conditions cementum hyperplasia develops.*

CHAPTER IV

EPITHELIAL ATTACHMENT, GINGIVAL CREVICE

Changes in the enamelorgan

During the enamel formation the enamel organ consists of ganoblasts, stratum intermedium, and the outer enamel epithelium. As the time approaches at which the tooth will erupt, the ganoblasts instead of remaining columnar in form, become cuboidal, then more and more flat until they are lost to sight. The top of the crown is then covered with a stratified squamous epithelium called the reduced enamel epithelium. The enamel is formed by ganoblasts, and each enamel rod is a calcified protoplasmic process of a ganoblast. The last product of the ganoblasts in this evolution is a cuticle called the primary enamel cuticle. *This cuticle is in organic connection with the enamel on the one side and with the reduced enamel epithelium on the other. No space exists between the enamel, the cuticle, and the reduced enamel organ.*

Reduced enamel epithelium and mouth epithelium grow together

As the tooth approaches the point of eruption, *the reduced enamel epithelum comes in contact with the mouth epithelium so that they grow together.* This stage of tooth development is shown in Fig. 91. We see the reduced enamel epithelium on the surface of what was formerly the enamel. The enamel is lost by decalcification and shows in the section as an empty space. The primary enamel cuticle lies in the space formerly occupied by the enamel. The reduced enamel epithelium shows the same characteristics as the mouth epithelium. Above the tip of the crown, the epithelium of the mouth and that of the enamel have grown together.

Eruption

As the eruption of the tooth proceeds, the epithelium overlying the tip of the crown degenerates, and the tooth breaks through into the mouth. Fig. 92. *The junction of the mouth epithelium with the enamel epithelium forms the free margin of the gum.*

Formerly it was supposed that after the tip of the crown had broken through the mouth epithelium, a space existed between the enamel epithelium and the enamel, which space extended to the cemento-enamel

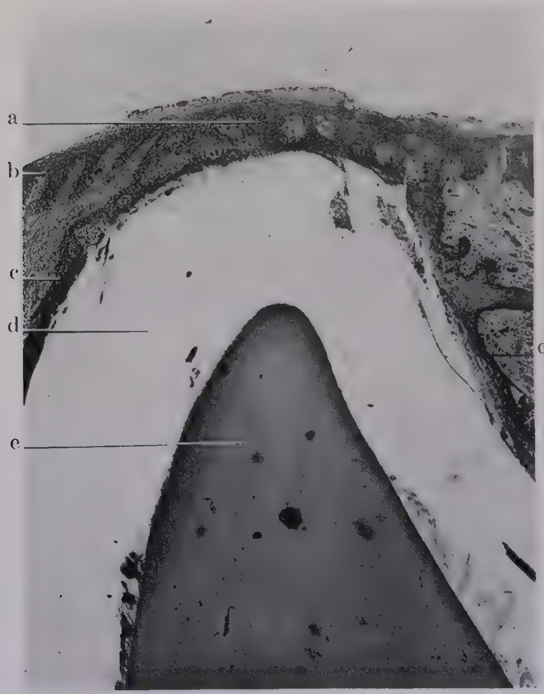


Fig. 91
Tooth preceding eruption.
At a the mouth epithelium (b) and enamel epithelium (c) have grown together.
d. enamel. e. dentin.

junction. (Called "sub-gingival space"). Since 1921 we know from the work of *Gottlieb* that this conception is false and that *no space exists between the enamel and the enamel epithelium. There is an organic connection between the enamel epithelium and the enamel,*

not only before but during tooth eruption. Previous to tooth eruption the epithelum connected with the enamel is known as the reduced enamel epithelium. Immediately after eruption, as the free margin of the gum and the crevice is formed, the same epithelium is called the "epithelial attachment". *The epithelial attachment is that portion of the epithelium surrounding the tooth which is in organic connection with the surface of the tooth.* In many cases after eruption has commenced, ganoblasts are still to be found in the epithelial attachment near the cemento-enamel junction. As eruption proceeds these ganoblasts also disappear. *Epithelial attachment*

During the succeeding eruption the epithelium physiologically separates from the enamel and forms the *gingival crevice.* A probe placed in the space between the epithelium and the enamel will not reach to the cemento-enamel junction, but stops at the point where the enamel epithelium is attached to the enamel or enamel cuticle. *The space limited on one side by the enamel or enamel cuticle and on the other by the epithelium, constitutes the gingival crevice. The lowest point of the separation is the bottom of the crevice. The epithelium bordering the gingival crevice is called the crevice epithelium. The part of the gum where the crevice epithelium passes over to the mouth epithelium is called the free margin or the crest of the gum.* *Gingival crevice*

The epithelium of the gum is a stratified squamous epithelium with a hornified layer on its surface. This hornified layer frequently extends into the gingival crevice. This epithelium with the underlying connective tissue forms deep papillae. No papillae are normally to be found on the epithelium forming the epithelial attachment. In the connective tissue under the bottom of the crevice we find almost universally a round cell infiltration. It is supposedly due to the constant irritation to which these tissues are exposed.

Fig. 92 shows the stage of tooth eruption in which the

top of the crown breaks through the degenerated epithelium. At "c" the bottom of the crevice is to be seen. In order to set forth the difference between the old conception of the gingival crevice and the

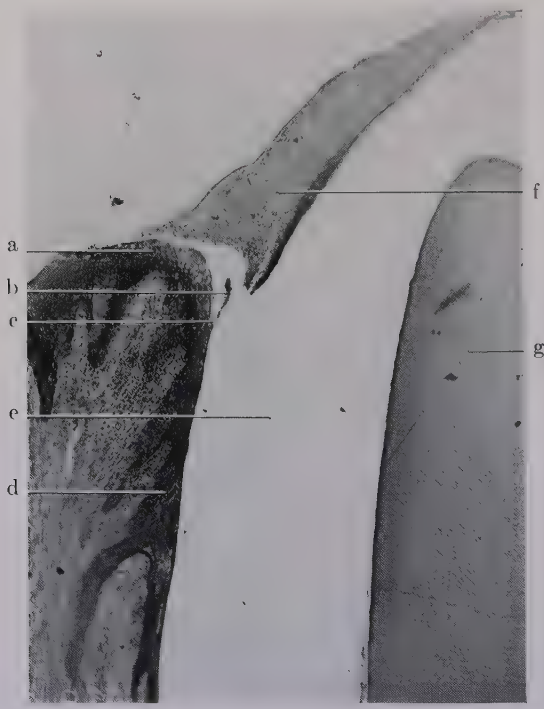


Fig. 92
The tip of the tooth is erupted.
a. free margin of gum.
b. enamel cuticle.
c. bottom of gingival crevice.
d. epithelial attachment.
e. enamel.
f. degenerated, hornified epithelium.
g. dentin.

newer conception of *Gottlieb*, the following diagram is presented. Fig. 93. *On the left side is illustrated the old conception.* The tooth has erupted and the bottom of the crevice is on the cemento-enamel junc-

tion (gingival line). *On the right side Gottlieb's view is presented.* The bottom of the gingival crevice is at the lowest point of the detachment of the epithelium attached to the enamel or enamel cuticle. From this point to the cemento-enamel junction the epithelium is in organic connection with the surface of the south and is known as the epithelial attachment. I emphasize this fact because of its importance for a proper conception of the pathology of so-called pyorrhea, and also because of its clinical significance in operative and prosthetic procedures.

After the tip of the crown appears in the mouth, the tooth eruption proceeds steadily until the tooth comes into occlusion. After this point is reached it is generally considered that eruption is completed. This conception also is false, as has been demonstrated by *Gottlieb.* For convenience we have classified tooth eruption into four stages. *At the time the erupting teeth come in contact with their antagonists, about one-third of the enamel is still in organic connection with the epithelium.* This lower third of the anatomical crown is therefore not erupted and the bottom of the crevice is on the surface of the enamel. *The erupted portion of a tooth is that part which is bathed by saliva.* In Fig. 94 the labial surface of an upper incisor is shown. *The bottom of the gingival crevice is on the surface of the enamel and the epithelial attachment ends at the cemento-enamel junction.* The epithelium has ended at this point since the development of the enamel. This constitutes the first stage in tooth eruption. Fig. 95 is a higher magnification of the gingival crevice, showing the connection of the enamel cuticle with the epithelium. The cuticle before the epithelial attachment separates, lies between the enamel and the epithelium and is in organic connection with both. The point where the epithelium separates from the cuticle is the bottom of the crevice. *The cuticle remains on the surface of the tooth.*

First stage of tooth eruption

Second stage of tooth eruption

The eruption, however, is not completed at this point, but it is a continuous process. The tooth eruption now enters the second stage. *The further separation of the epithelium from the enamel and a downward growth of the epithelial attachment beyond the cemento-*

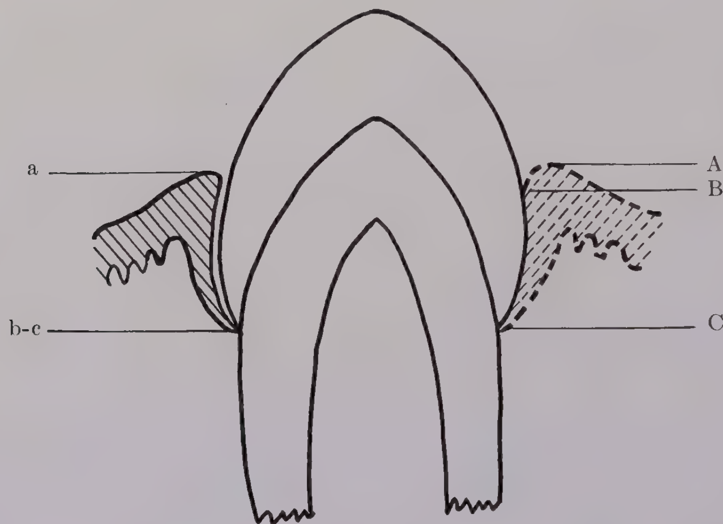


Fig. 93

Diagram showing old and new conception of the attachment of epithelium to the tooth.
Left side—old conception.
a. free margin of gum.
b. attachment of epithelium, bottom of crevice at the cemento-enamel junction (c).
Right side—new conception.
A. free margin (crest of the gum.) B. bottom of gingival crevice.
C. cemento-enamel junction. From B to C is the epithelial attachment.

enamel junction mark the beginning of the second stage of tooth eruption. This is shown in Fig. 96. We see part of the epithelial attachment covering the cementum. The epithelium is attached to the cementum similarly as it is to the enamel. *The entire enamel is not yet erupted. The bottom of the crevice is still on the*

surface of the enamel. As eruption continues, the whole epithelial attachment shifts apically. The bottom of the crevice may be found on the cemento-enamel junction.

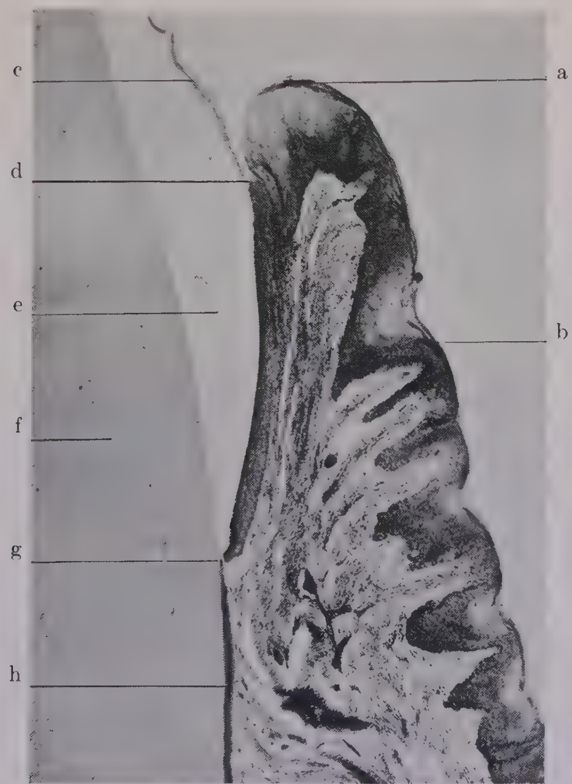


FIG. 94
First stage of tooth eruption.
Bottom of the crevice (d) on the enamel (e) deepest point of the epithelial attachment on cemento enamel junction (g).
a. free margin of the gum. b. mouth epithelium.
c. enamel cuticle. f. dentin. h. cementum.

Third stage of tooth eruption

This is the third stage of tooth eruption. Fig. 97. *The lowest point of the epithelial attachment is found on the surface of the cementum.* The bottom of the crevice

does not remain at the cemento-enamel junction any longer than it does at any other points on the surface of the tooth. The cemento-enamel junction is only a line. The bottom of the crevice passes this line as

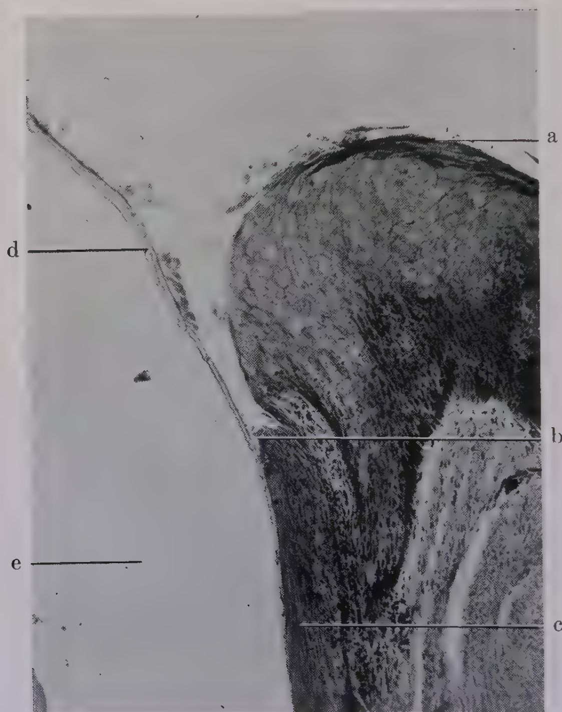


Fig. 95
Higher magnification of Fig. 94.
a. free margin of the gum.
b. bottom of gingival crevice.
c. epithelial attachment.
d. enamel cuticle.
e. enamel.

it does every other point on the surface of the tooth, so that this stage is rarely ever found. This stage marks only a moment in the continuous growth of the tooth. *During further eruption, as soon as the bottom*

of the crevice passes the cemento-enamel junction, cementum is exposed. The exposure of cementum indicates

Fourth stage of tooth eruption

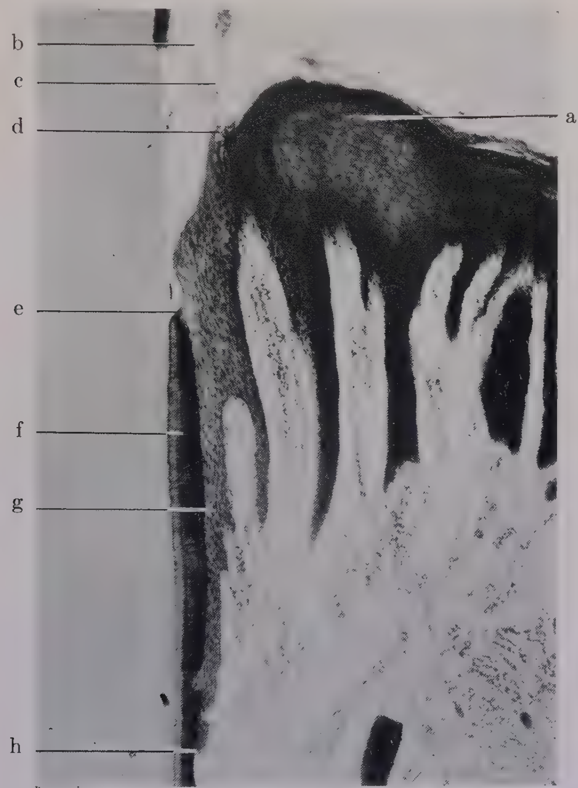


Fig. 96
Second stage of tooth eruption.
Bottom of gingival crevice (d) on the enamel (b) deepest point of the epithelial attachment (h) on the cementum.
a. mouth epithelium.
c. enamel cuticle.
e. cemento-enamel junction.
f. cementum.
g. epithelial attachment.

the fourth stage of tooth eruption. This is marked by the bottom of the crevice passing the cemento-enamel

junction, and the deepest point of the epithelial attachment is still closer to the apex. This is seen in Fig.

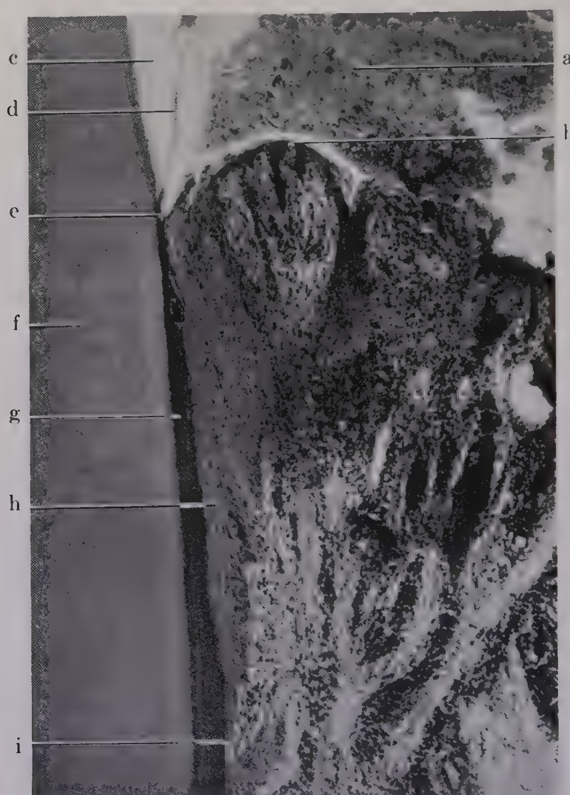


Fig. 97
Third stage of tooth eruption.
Bottom of gingival crevice (e) at the cemento-enamel junction (e) deepest point of epithelial attachment on the cementum (i).

a. calculus.
b. free margin of the gum.
c. enamel.
d. enamel cuticle.
f. dentin.
g. cementum.
h. epithelial attachment.

98. *The rate of eruption differs with various persons and in different teeth of the same individual. It is not*

possible to find any case in which the bottom of the crevice is found to be identical with the deepest point of the

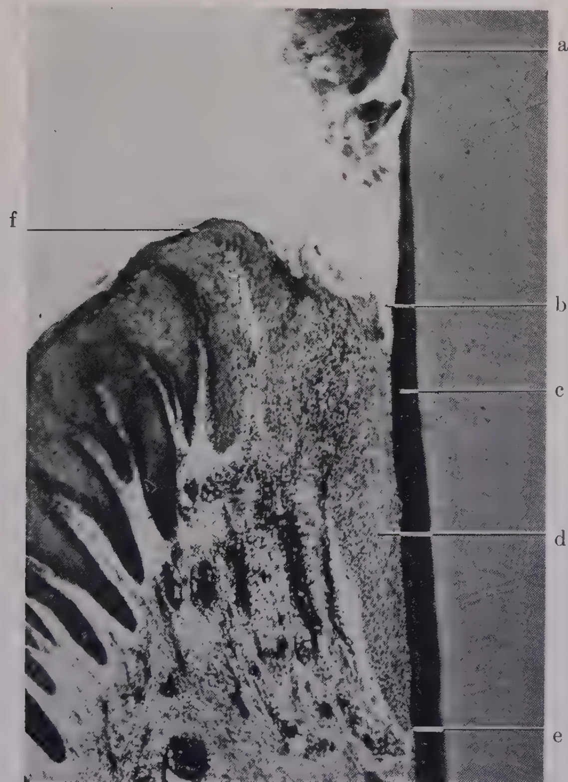


Fig. 98
Fourth stage of tooth eruption.
Bottom of gingival crevice (b) on the cementum (c) deepest point of the epithelial attachment (e) on the cementum.
a. cemento-enamel junction.
d. epithelial attachment.
f. free margin of the gum.

epithelium. The epithelium is never attached to the tooth at one point only, shown in diagram 93 at the left, but covers a considerable portion of the tooth

as shown at the right. In order to avoid any misapprehension it is necessary to emphasize the fact that crevice formation progresses at an unequal rate on the different surfaces of the teeth. For example, it is never possible to find the bottom of the crevice at the cemento-enamel junction on all surfaces of the tooth simultaneously. *The rate of eruption is an important factor in this process. If the process pro-*

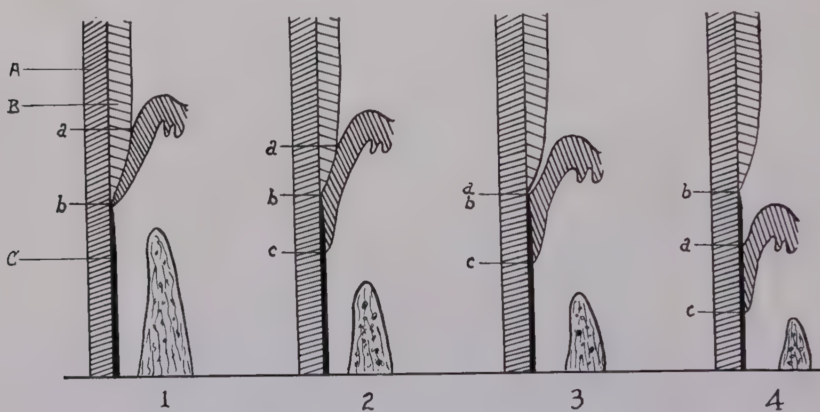


Fig. 99
Diagram showing the four stages of tooth eruption.

A. dentin.
B. enamel.
C. cementum.

a. bottom of crevice.
b. cemento-enamel junction.
c. deepest point of epithelial attachment.

ceeds slowly it is in the realm of physiology but if it becomes rapid, it passes over into the pathologic state. Therefore, the slower the process the more favorable the outlook for the teeth.

The conception of tooth eruption may be summarized in diagram, Fig. 99, 1, shows the first stage of tooth eruption. The bottom of the crevice is on the surface of the enamel at "a"; the deepest point of epithelial attachment is at the cemento-enamel junction (b). In this connection I will describe more fully what we mean by the *clinical crown and*

the anatomical crown. The anatomical crown is the enamel covered part of the tooth, the clinical crown is the portion of the tooth which projects above the bottom of the crevice and is bathed with saliva. During the first stage of eruption the clinical crown is smaller than the anatomical crown. In the second stage of eruption (2 in the diagram) the deepest point of the epithelial attachment (c) is beyond the cemento-enamel junction (b) and it grows deeper along the cementum. The bottom of the crevice is still on the surface of the enamel at a. The clinical crown is still smaller than the anatomical crown. During the third stage of tooth eruption (3 in the diagram) the bottom of the crevice is found on the cemento-enamel junction, and the deepest point of the epithelial attachment (c) is still deeper on the surface of the cementum. The anatomical and clinical crowns are identical. In the fourth stage of eruption (4 in diagram) both the bottom of the crevice and the deepest point of the epithelial attachment are found below the cemento-enamel junction. The clinical crown in this stage is larger than the anatomical crown and consists, in part, of cementum.

Anatomical crown and clinical crown

Because the rate of eruption varies, it is very difficult to coordinate the different stages with ages. In general the first stage is found approximately up to the age of twenty-five, the second stage corresponds to the ages 25-35. Beyond the ages of 35-40 the fourth stage is common. In spite of all this, we may find in individuals of 20 the fourth stage of eruption, and in individuals of 50 the first stage.

In the chapter on enamel it was mentioned that *the ganoblasts before they disappear build a membrane called the primary enamel cuticle.* Fig. 30 shows this cuticle. *This membrane is about one micron in thickness.* Since it is a product of the ganoblasts this cuticle has the same properties as the organic matrix of the enamel, and may also become calcified. This fact probably

Primary enamel cuticle

accounts for the extensive discussion that this cuticle has aroused regarding its existence and nature. Some investigators have seen it, others have not. If it is calcified it may become lost during decalcification. Some investigators have described the enamel cuticle (known as *Nasmyth's* membrane) as a cement layer covering the surface of the enamel. (*Nasmyth*, *Owen*, *J. and Ch. Tomes*). Other investigators (*Kolliker*, and *Ebner*) believe the cuticle to be a product of the ganoblast and claim that it is resistant to acids and alkalies. *Waldeyer* describes it as originating from the outer enamel epithelium and being hornified. Similar opinions were held by *Hopewell-Smith*, *Mummery* and *Boedecker*.

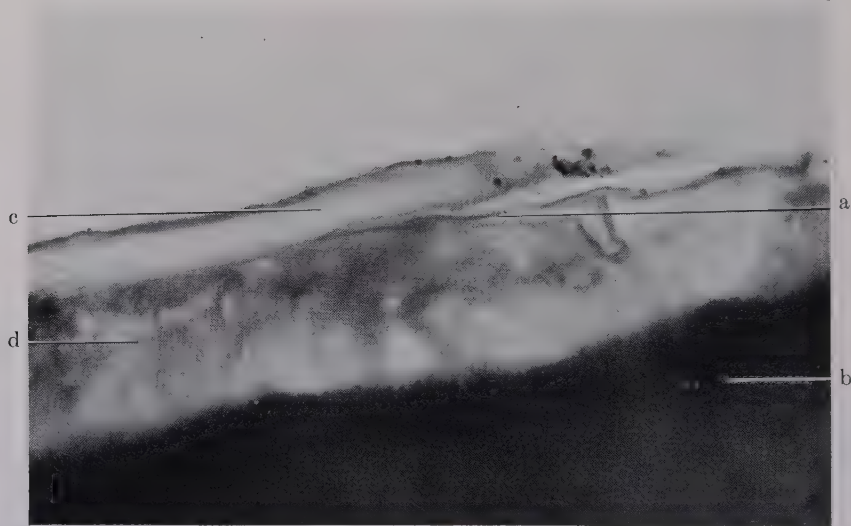


FIG. 100
Primary (a) and secondary (c) enamel cuticle.
b. dentin. d. enamel.

Gottlieb states that not only one, but two cuticles exist. The inner layer which we call the primary

cuticle is built by the ganoblasts; it is an organic membrane and may become calcified. This membrane is not a keratinous substance and is no more resistant to acids and alkalies than the organic matrix of the

Fig. 101
Cuticula dentis (a) covering enamel (b) and the cementum (c).
d. cemento-enamel junction.
e. dentin.
f. crevice epithelium.

enamel or the enamel itself. But *there is another cuticle outside of the primary cuticle which is built during the process of tooth eruption by the stratified squamous epithelium of the epithelial attachment and is called* *Secondary enamel cuticle*

"*secondary enamel cuticle*". *This cuticle by reason of its origin is a keratinous substance and is resistant to acids and alkalies. It may be from 2-10 micra in thickness.*

It is very rare to find the two cuticles in the same specimen, because the primary cuticle almost invariably disappears with the enamel during decalcification. Frequently the secondary cuticle is not formed. The epithelial attachment does not always build a hornified cuticle, and we do not know why in one instance the cuticle fails to appear and in another instance develops fully. In Fig. 30 we have already seen the primary cuticle and in others (Fig. 37, 39) the secondary. Fig. 100 shows both in one specimen. The thin primary cuticle may be followed under the thicker hornified secondary cuticle.

The epithelial attachment is found not only on the enamel but on the cementum in the 2nd, 3rd, and 4th stages of eruption. The hornified cuticle therefore may be built not only on the enamel but on the root. In Fig. 101 the cuticle may be seen covering both enamel and cementum.

Cuticula dentis

Because this secondary cuticle is found on both enamel and cementum it is called the cuticula dentis. It is evident that *the hornified cuticle can only be found on the portion of the cementum where the epithelial attachment has passed in its downward growth.* To summarize, we may state that there are two types of enamel cuticles, primary and secondary. The primary cuticle covers the enamel only, the secondary cuticle may cover both enamel and cementum.

F. T. Paul and *Mummery* described the *Nasmyth* membrane also, as a double layer, but claim that the outer layer is composed of epithelium. However, we known now that this epithelium described as the outer membrane is nothing more than a torn-away epithelial attachment. Or in *some animals* a layer of not hornified epithelium.

It is opportune at this time to discuss the normal gingival crevice. The gingival crevice is the space between the gum and the tooth. It is bounded on one side by the crevice epithelium from the free margin of the gum to the beginning of the epithelial attachment, and on the other side by the enamel, or if present, by the enamel cuticle. If the bottom of the crevice has passed the cemento-enamel junction, the inner border of the crevice is formed by the surface of the cementum or by the cuticula dentis if it is built. To determine the "normal" is almost impossible. Physiologic and pathologic conditions are constantly merging so that it is difficult to define the limits between the two. In the description of the normal crevice I refer to measurements made in 356 cases on microscopic specimens of human teeth. The measurements were made on gingival crevices which showed no pathology viz. formations of ulcers on the crevice epithelium. Fifteen cases measured showed no crevice at all; the bottom of the crevice and the free margin of the gum were identical. In 17 cases crevices varied from 0.0 to 0.10 mm.

Gingival crevice

The depth of the crevice

129 crevices ranged between 0.10-0.50 mm.
102 crevices ranged between 0.50-1.00 mm.
17 crevices ranged between 1.00-1.50 mm.
21 crevices ranged between 1.50-2.00 mm.
13 crevices ranged between 2.00-3.00 mm.
0 crevices ranged between 3.00-4.00 mm.
1 crevice ranged between 4.00-5.00 mm.
1 crevice ranged between 5.00-6.00 mm.

From these measurements it is evident that 45% were less than 0.5 mm. deep, 29% between 0.5 and 1.00 mm. deep, and about 26% were deeper than 1.00 mm. The average crevice is about 0.80 mm. deep. The material was obtained from corpses of the lower classes. Very little evidence of mouth hygiene could be noted. Although I doubt whether we can say that the average normal crevice is 0.80 mm. in depth, we

can surely say that *a gingival crevice can scarcely be too shallow.* (*Gottlieb*). *The ideal crevice approaches 0.0 mm.* In microscopical specimens the best conditions of the investing tissues were found in those cases where crevices were shallowest. The tendency to pathologic conditions was observed in the deeper crevices. This observation can be verified clinically. It is our task to obtain for our patients these ideal conditions. The factors which favor these ideal conditions are a well developed cuticula dentis, and a well hornified epithelium to the bottom of the gingival crevice.

The causes which lead to the downward growth of the epithelium along the cementum are the subject of serious debate. Inflammation, trauma, etc. are claimed as primary causes. In this connection I shall not attempt to repeat the discussion, but state only that the downward growth of the epithelium along the cementum is a fact. I believe with *Gottlieb* that the primary factor which leads to this epithelial downward growth is the progressive involution of the surface of the tooth, especially that of the cementum.

CHAPTER V

PERIODONTAL MEMBRANE

The periodontal membrane consists of connective tissue fibers which chiefly form the union between

Fig. 102
Interdental septum. Peridontal membrane.
a. cemento-enamel junction. c. alveolar crest fibers.
b. transeptal fibers. d. oblique fibers.
e. alveolar process.

the tooth and alveolar bone. This connective tissue produces through the cementoblasts the cementum, and through the osteoblast the alveolar bone. The

fibers of the periodontal membrane are collagenous in nature, and not elastic as has been frequently stated.

Principal fibers

The embedding of the connective tissue fibers in the cementum and the bone forms the connection

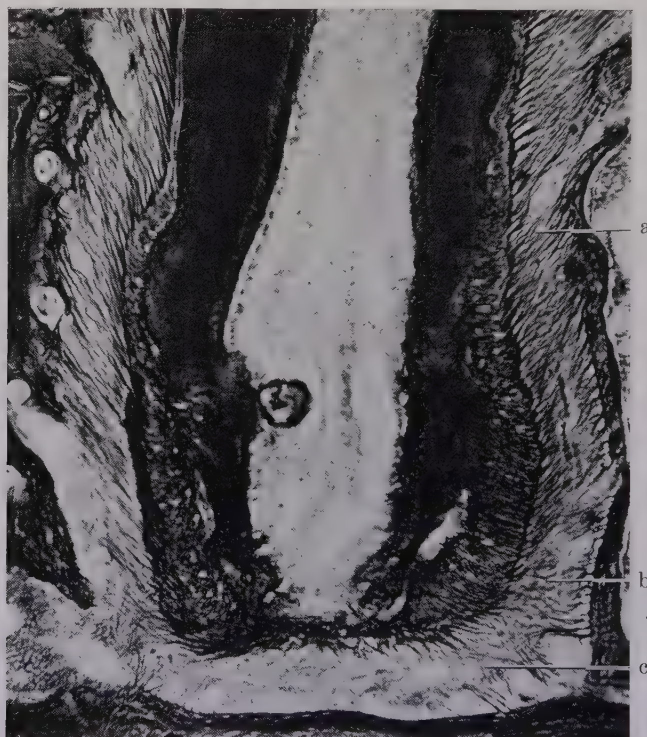


Fig. 103
Apical group of fibers (c).
b. horizontal group. a. oblique group.

between the two. *G. V. Black* in his detailed study of this subject classified the groups of fibers of the periodontal membrane into free gingival, transseptal, alveolar crest, horizontal, oblique, and apical groups. These fibers he called the principal fibers in differentia-

tion from the indefinite connective tissue fibers and cells which follow blood vessels, lymph vessels, and nerve fibers. Fig. 102 illustrates the principal fibers *Indefinite fibers*

Fig. 104
Principal (c) and indefinite (d) fibers in the periodontal membrane.
a. dentin. b. cementum. e. alveolar bone.

in an interdental septum. Fig. 103 shows the additional apical group. The indefinite fibers, which surround nerve fibers, blood and lymph vessels are to be observed in Fig. 104. In this illustration we

may observe the slightly wavy course of the principal fibers. This suggests that the fibers are not stretched when the tooth is not in function but permits a slight movement of the tooth upon the application of stress. Fig. 105 a section from the apical region shows the

Fig. 105
Peridontal membrane fibers near to the apex.

co-relationship between the periodontal fibers and the other structures of the periodontal membrane in cross section. From this section we can readily visualize the resistance offered against a rotary movement. Investigations have shown that the periodontal membrane with its fibers does not show the same structure

on the whole circumference of the tooth. The structure of the periodontal membrane depends upon the physiologic movement of the teeth which will be described later. The fibers of the periodontal membrane are

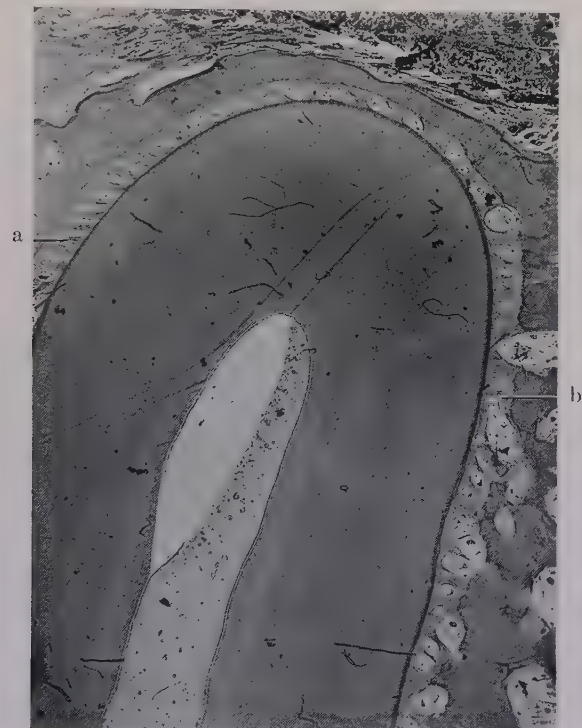


Fig. 106
The shape of the spaces in the periodontal membrane depends on the tension and relaxation of the principal fibers.
a. side of tension—long spaces.
b. side of relaxation—round spaces.

stretched on those surfaces from which the teeth are moving or wandering. On the tension side the spaces occupied by the blood vessels, nerve fibers, and lymphatics are elongated as a result of the pressure exerted

by the stretched fibers. On the pressure side the fibers are relaxed and the spaces round.

Blood-lymph supply

A cross section of a root of a tooth Fig. 106 shows the difference between the fibers and spaces due to the tension and relaxation of the fibers. Fig. 107 shows

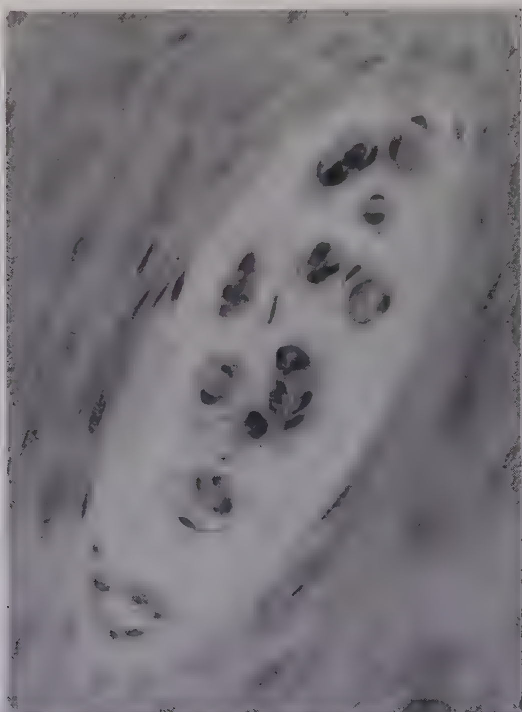


Fig. 107
Space in the periodontal membrane. Blood vessels, nerve fibers.

the blood vessels, and lymph vessels surrounded by soft connective tissue from Fig. 106 more highly magnified. This picture illustrates a characteristic behavior of the capillaries in the periodontal membrane. The investigations of *Schweitzer* have shown that the capillaries form interwoven groupings comparable

to the glomeruli of the kidney. It is important to know that the blood supply of the periodontal membrane comes from different sources. One source is

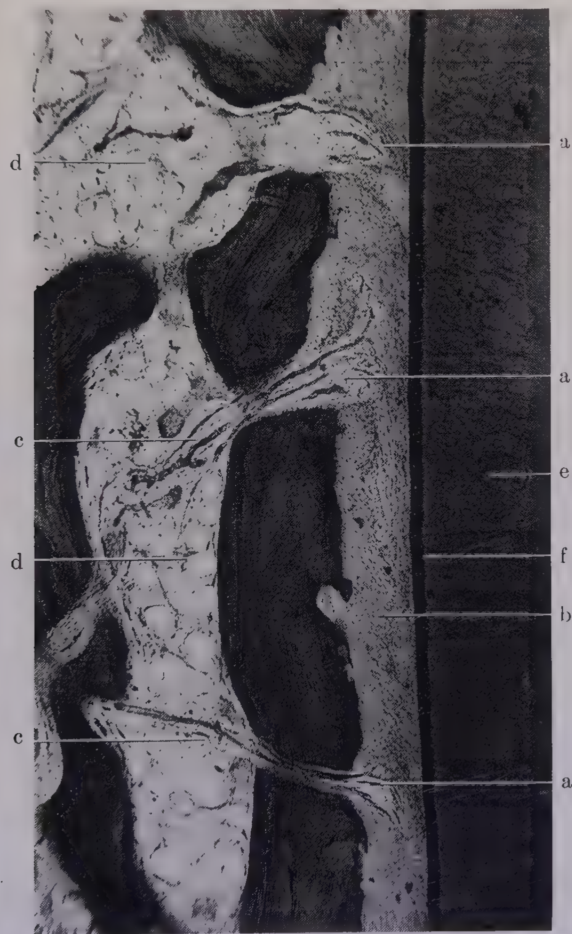


Fig. 108
The blood vessels (a) of the periodontal membrane (b) communicate with the blood vessels (c) of the adjacent marrow spaces (d).
e. dentin. f. cementum.

from the apical region which is common with the blood supply of the pulp. The main supply however is derived from the marrow spaces bordering the alveolus by a liberal anastomosis with the vessels of the periodontal membrane. Fig. 108 illustrates this

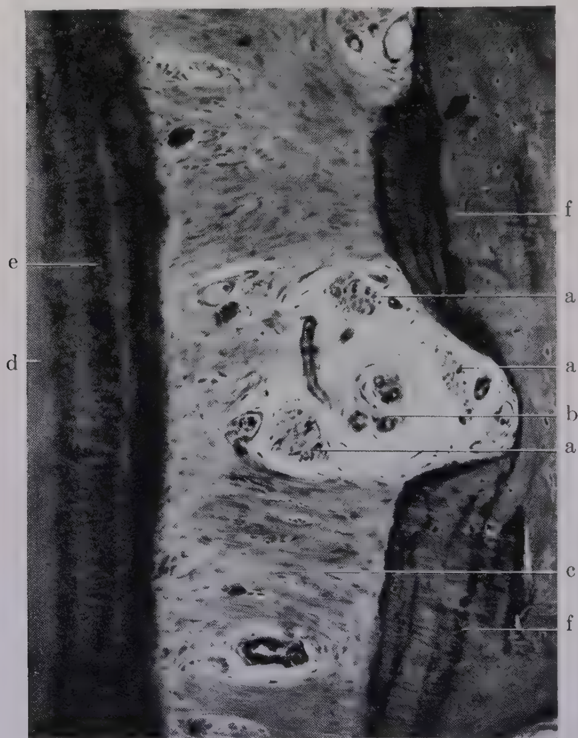


Fig. 109
Nerve fibers (a) and blood vessels (b) in the periodontal membrane (c).
d. dentin. e. cementum. f. alveolar bone.

anastomosis. The vessels of the periodontal membrane as well as the soft tissues surrounding them perform a mechanical function in addition to the nutritional function. In the movement of the teeth they

act as elastic cushions that act as shock absorbers to mechanical influences.

Nerve supply

The chief nerve fibers of the periodontal membrane originate from the same branches as those of the pulp. They are medullated in all but their terminal branches, which are free from myelin sheaths. Fig. 109 illustrates the bundles of medullated nerve fibers in the neighborhood of blood and lymph vessels.

The periodontal membrane suspends the teeth in their alveoli. The teeth through this type of fixation are not absolutely immobile but have a movement. The degree of this movement depends mainly upon two factors; first, the width of the periodontal membrane, and second, the height of the alveolar process in relation to the size of the root. The narrower the periodontal membrane and the higher the alveolar process, the tighter will be the tooth. Conversely when the membrane is wide and the process is low, the tooth is also correspondingly loose. However, a wide periodontal membrane is not necessarily combined with a low alveolar process.

Thickness of the periodontal membrane

In the same manner as it is difficult to determine the normal depth of a gingival crevice it is also difficult to determine the normal thickness of the periodontal membrane. The general statement is true that *the narrower the periodontal membrane and the higher the alveolar process, the more firm the tooth.* Measurements obtained from an extensive material yield only approximate averages. The average thickness of the periodontal membrane in the upper as well as the lower jaws is 0.23-0.25 mm. (A. Klein.) This varies with the age. The periodontal membrane appears to become wider with age. At the alveolar margin the periodontal space is wider than at the middle of the alveolus, and at the apex the space is again wider than it is at the middle. Average measurements obtained are: at the margin, 0.39 mm., at the middle of the alveolus 0.17 mm. and at the apex about 0.21 mm. *The narrowest place in*

the periodontal membrane is a little below the middle of the alveolus in the majority of cases. *This signifies that the fulcrum of the tooth is at this place* and not at the alveolar margin. This has been experimentally shown by *A. M. Schwarz.* It is interesting to note that in the anteriors and bicuspids, the periodontal membrane is wider on the mesial surfaces at the alveolar margin, and wider at the middle than it is on the distal surfaces on the same teeth. At the apices the periodontal space on the mesial surface is narrower than it is at the distal surface. This fact is probably due to the physiologic mesial wandering of the teeth which will be described later. These differences are not so apparent on the distal and mesial surfaces of molars.

Epithelial rests

Epithelial structures in the periodontal membrane described by Malassez may be seen normally in all cases. They are found as epithelial rests near the surface of the cementum but very seldom in contact with it. (Fig. 110).

To understand the origin of these groups of epithelial cells it is necessary to refer to the development of the enamel and the enamel organ. The enamel organ is developed by epithelium, remainder of which covers the enamel during the whole developmental process up to the time the full anatomical crown is erupted. In a toothgerm in which the formation of dentin and enamel has begun we see at the apical end of the toothgerm *the outer enamel epithelium passing over into the inner layer and there forming a loop.* (Fig. 111.) *This loop is called Hertwig's epithelial sheath.* It surrounds the apical end of the growing tooth as a sheath. *The epithelium of the enamel* does not end where the enamel ends, but enamel epithelium *is also found during development of the root dentin at its apical region, up to the time the apex is fully developed. Brunn* made the statement which later investigators verified, that *no dentin can be built without this epithelial sheath.* The epithelium

Hertwig's epithelial sheath

is probably necessary to stimulate the connective tissue of the pulp to form odontoblasts and thus dentin.

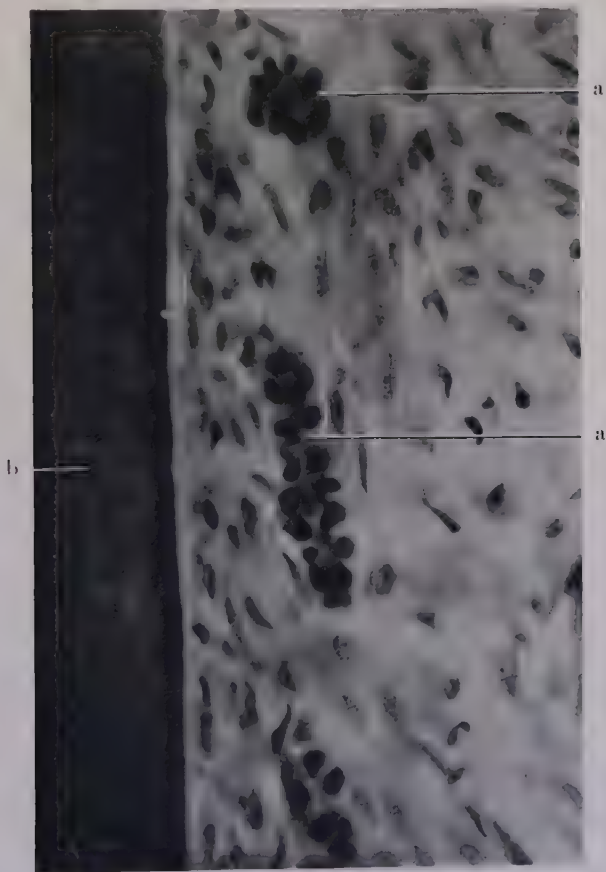


Fig. 110
Epithelial rests (a) in the periodontal membrane.
b. cementum.

It has been thought that after the anatomical crown is formed the end of the enamel organ, or Hertwig's epithelial sheath, grows into the depths of the connec-

tive tissue and prepares the way for the root. It was stated that the epithelium sheath remains unbroken

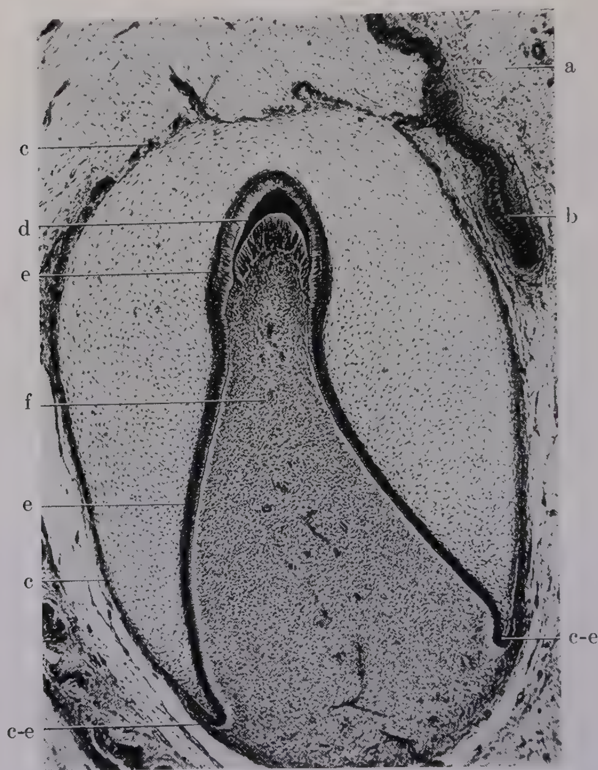


Fig. 111
Toothgerm of a 200 mm. human embryo.
a. dental lamina.
b. bud for permanent tooth.
c. outer enamel epithelium.
d. dentin.
e. inner enamel epithelium (ganoblasts).
f. dental papilla (pulp).
c-e. the outer and inner enamel epithelium are continuous. (Hertwig's epithelial sheath).

as a continuous sheath until it is broken up by the connective tissue which invades the sheath to form the cementum. It was believed that the epithelial rests

FIG. 112
Deciduous tooth of 3 years old child. The deepest points of the permanent toothgerms are about 1.5 mm. from the floor of the nose.

FIG. 113
Deciduous tooth of 4 years old child. The deepest points of the permanent toothgerms are about 1.0 mm. from the floor of the nose.

FIG. 114
Deciduous tooth of 7 years old child. Deepest points of the roots are about 1.5 mm. from the floor of the nose.

FIG. 115
Deciduous tooth of 12 years old child. The apices of the teeth are about 1.0 mm. distant from the floor of the nose.

seen at all ages are the remainders of this destroyed epithelial sheath.

The "fixed point" during development

This conception has been changed as a result of newer investigations. *Hertwig's epithelial sheath does not grow into the depth but constitutes a relatively fixed point during the development of the teeth.* Measurements made between *Hertwig's* epithelial sheath and the floor of the nose show that the epithelial sheath and therefore also the root does not grow into the depth. The four following photographs show different stages in the development of the roots; the ends of the roots

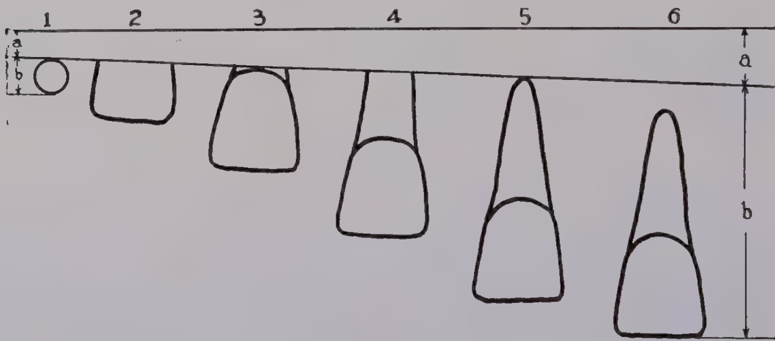


Fig. 116
Diagram showing that the "fixed" point in tooth development is Hertwig's epithelial sheath. The growth proceeds toward the periphery.

are approximately at the same distance from the floor of the nose in all of these stages. (Figs. 112, 113, 114, 115.) This developmental process is diagrammatically shown in Fig. 116. "a" is the distance between *Hertwig's* epithelial sheath and the floor of the nose; "b" represents the length of the tooth. "a" has changed very little, it has increased somewhat, and it is very important to note that it has not decreased. This is evidence that the root has not grown into the depth. The greatest increase in growth takes place at "b" which represents the length of the developing tooth of the different stages. The *Hertwig's* epithelial

sheath is the relatively fixed point. In consequence of these facts our opinion concerning *Hertwig's* epithelial sheath and the origin of the epithelial rests must

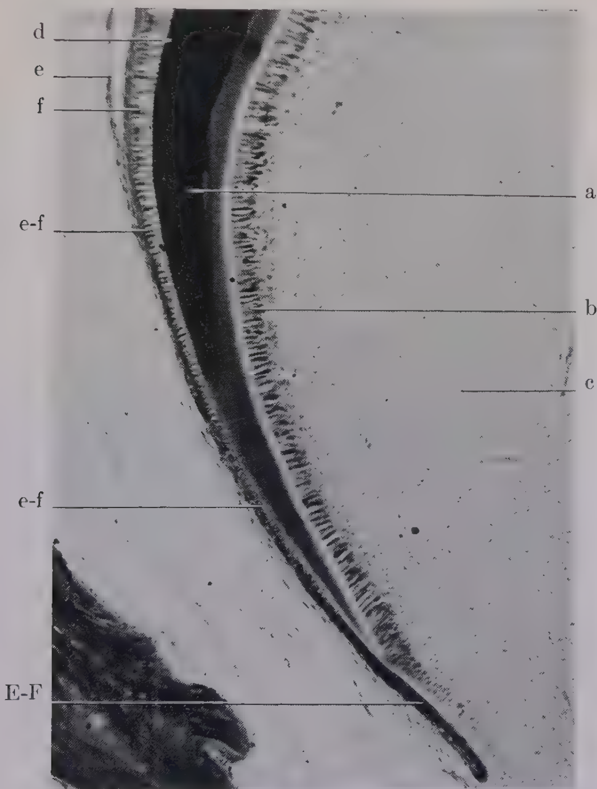


Fig. 117
Hertwig's epithelial sheath (E-F) is a continuation of the outer (e) and inner (f) enamel epithelium.
a. dentin. c. pulp.
b. odontoblast. d. enamel.

be revised. *A continuous epithelial sheath* as shown in Fig. 117 *is only to be seen at the beginning of root formation. As development progresses, and the root elongates, the connection between Hertwig's epithelial sheath (the*

loop) and the enamel is severed. The enamel organ ends

Fig. 118
The continuation between the enamel peithelium (b) and Hertwig's epithelial sheath (h) is broken.
a. enamel. e. periodontal membrane.
c. cemento-enamel junction. f. dentin.
d. alveolar bone. g. pulp.

Origin of epithelial rests

with the enamel, Hertwig's epithelial sheath remains as a loop on the end of the root (Fig. 118) *separated from*

the enamel epithelium. The epithelial rests remain between the enamel organ and Hertwig's epithelial sheath (Fig. 119) *indicating the former continuous connection.*

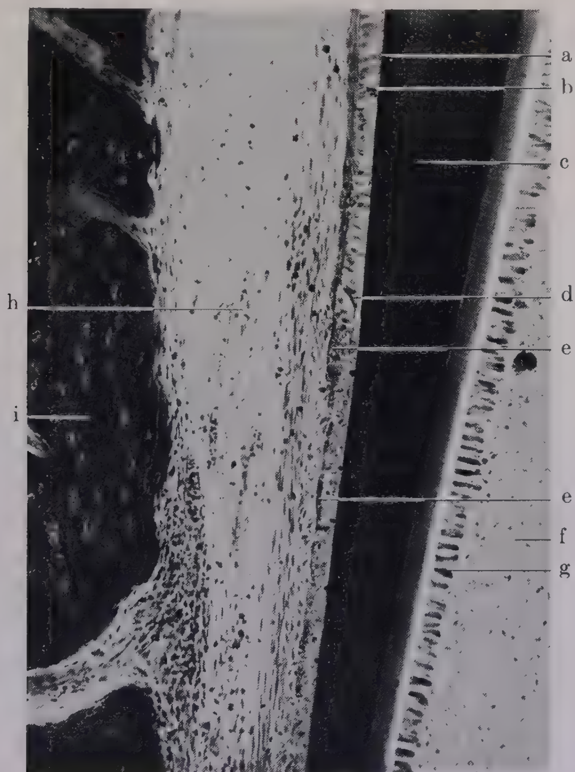


Fig. 119
The epithelial rests (e) may be followed to the enamel epithelium (b).

a. enamel.
c. dentin.
d. end of the enamel epithelium.
f. pulp.
g. odontoblast.
h. periodontal membrane.
i. alveolar bone.

A diagram Fig. 120 will clarify this process. The fixed point in the development of the root is the epithelial sheath of Hertwig. At "1" we see a toothgerm consisting of enamel epithelium. At "2" dentin and

enamel are being built, and under the end of the dentin the epithelial sheath of Hertwig ends as a loop. "3" shows the tooth further developed. The distance between the tip of the enamel and Hertwig's epithelial sheath is increased. The connection between the loop and the enamel epithelium is broken and only epithelial rests remain where earlier connections existed. At "4" the succeeding stage shows the root further developed, more epithelial rests lying between the loop and the enamel epithelium. The epithelial rest

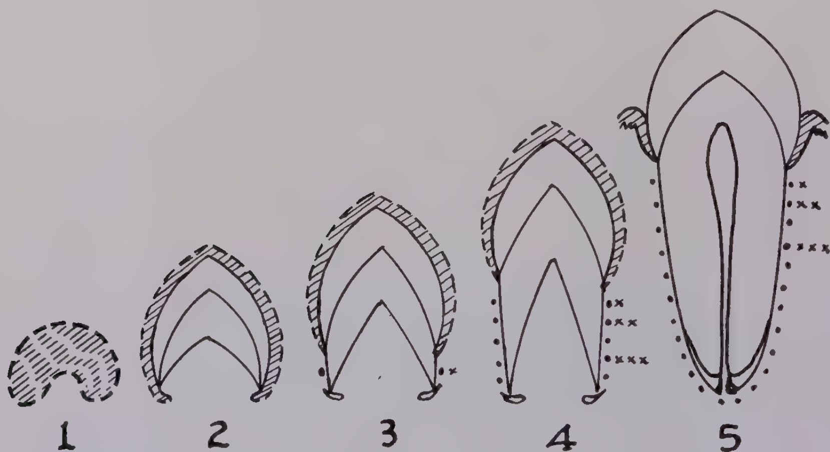


Fig. 120
Diagram illustrating the development of the epithelial rests during growth of root. Description in text.

"x" in the stage "3" is at "x" in the stage "4"; it has been carried along with the tooth. The epithelial rest at "xx" in "4" has been similarly carried along in "5". It is apparent that there is no continuous epithelial sheath along the root, and that epithelial rests do not originate as a result of the invasion of connective tissue into the sheath.

My conception of this process is that cell divisions in the epithelial sheath of Hertwig do not take place as rapidly as growth of the tooth, therefore no con-

tinuous epithelial sheath can be formed. The tooth grows out of its former sheath. Groups of epithelial cells from the end of the sheath are carried from the connective tissue closely surrounding the growing

Fig. 121
Periodontal membrane of a growing toothgerm, showing three layers.
a. bone fibers. d. bone.
b. tooth fibers. e. dentin.
c. intermediate plexus.

root. These groups of epithelial cells are the epithelial rests. As soon as the dentin is fully developed the function of the epithelial sheath is completed, and it disappears, leaving epithelial rests only to indicate its former existence.

Periodontal membrane of tooth germs

The epithelial rests are found in growing teeth in the inner layer of the periodontal membrane. The periodontal membrane of a *growing* toothgerm consists of three layers—the outer layer containing bone fibers, the inner layer containing the tooth fibers, and the ~~intermediate layer~~ forming the plexus or junction of the fibers of the other two layers. Fig. 121 will illus-

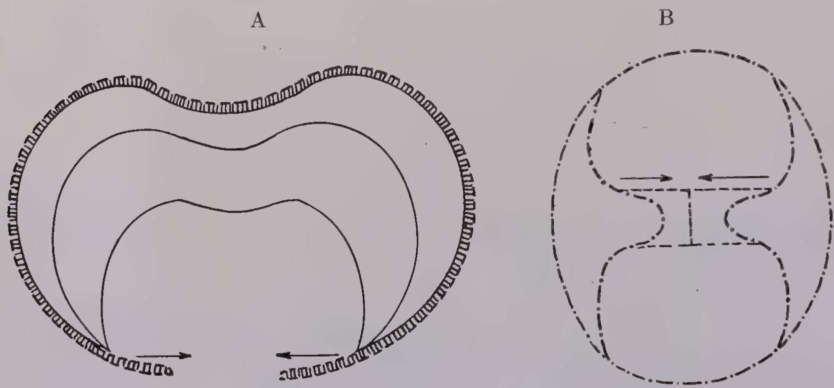


Fig. 122

Diagram showing origin of bifurcation of multi-rooted teeth.

A. Toothgerm from the side. Dotted line indicates enamel epithelium and Hertwig's epithelial sheath.

B. The toothgerm from the side of Hertwig's epithelial sheath which is indicated by the –.–.– line. The arrows indicate the direction of growth of Hertwig's sheath.

trate the three layers. The arrangement of the periodontal membrane fibers around a growing toothgerm permit the shifting of the tooth in its surrounding bone crypt. In the inner layer, the tooth fibers move together with the tooth and carry the epithelial rests with them.

I emphasized the fact that the epithelial sheath does not grow into the depths in the course of tooth development. However, this fact does not contradict activity in the epithelium. The epithelium seems to have an important influence in the developing of the shape of the tooth. Also, in the development of the bifurcation of multi-rooted teeth the activity of the epithelium

is undoubtedly important. The epithelium which influences the pulp cells to build the bifurcation comes from the side of the *Hertwig's* sheath and grows in a horizontal direction as indicated in Fig. 122a and b. Finally the epithelial sheath from both sides grows

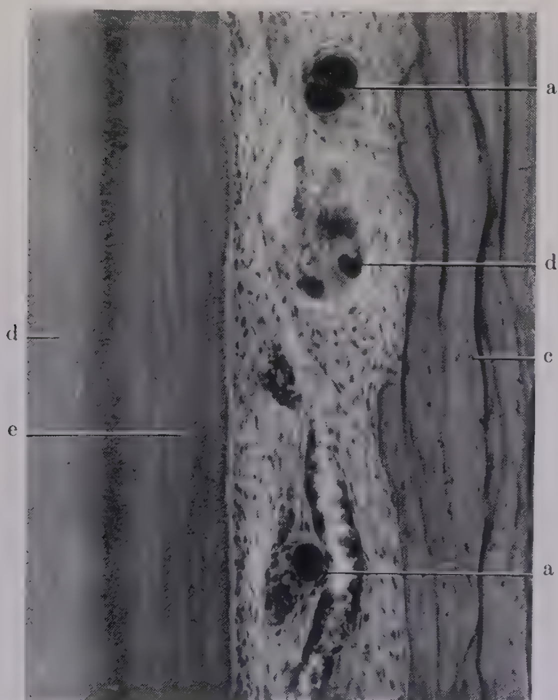


Fig. 123
Cementicles (a) in the periodontal membrane.
b. developing cementicles. d. dentin.
c. alveolar bone. e. cementum.

together as indicated in diagram 122b by the dotted line and the arrows. This junction constitutes the starting point for the development of the bifurcation and roots.

In the periodontal membrane of almost every specimen

Cementicles *from human jaws, we find round calcified bodies, the so-called cementicles.* The number of these cementicles varies in different cases. Frequently we find only a few of them, at other times we find them in great

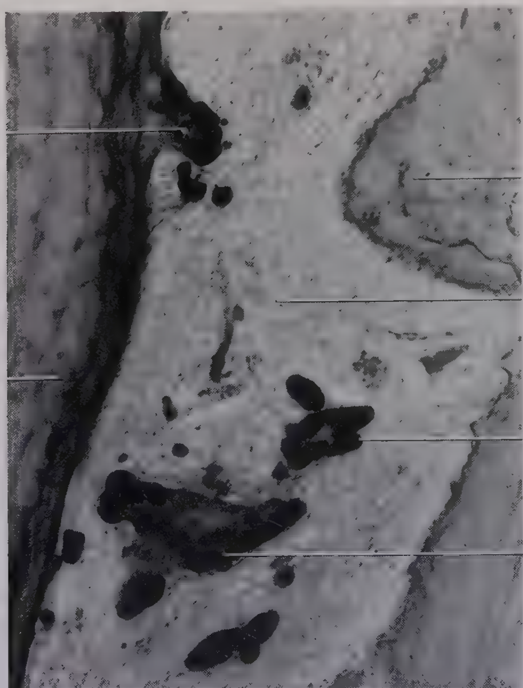


Fig. 124
Large free (c) and adherent (e) cementicles in the periodontal membrane (b).
a. alveolar bone. d. cementum.

abundance. The photomicrograph Fig. 123 illustrates cementicles *free* in the periodontal membrane. These bodies often remain free in the connective tissue throughout life, though frequently they become connected with the cementum. The cementum, as it thickens during life, envelops the cementicles and in this way

they become first adherent, and later enclosed in the cementum. *Adherent* cementicles are visible in Fig. 124. In the same specimen we observe large masses of cementicles free in the periodontal space. The

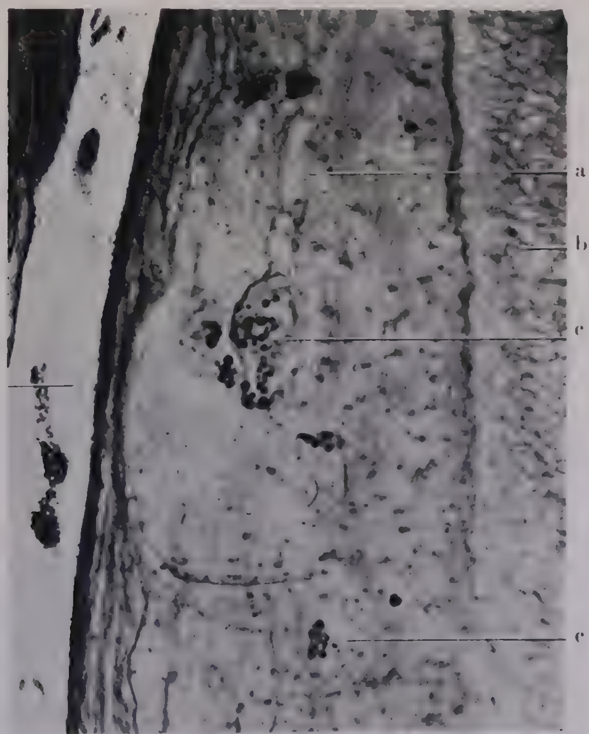


Fig. 125
Interstitial cementicles (c).
a. cementum. b. dentin. d. periodontal membrane.

cementicles may increase in size, grow together, and in this way form large masses. If these large masses of cementicles become adherent to the cementum they are called *cement exostosis*. Adherent cementicles when completely enclosed by the cementum are called *interstitial* cementicles, illustrated in Fig. 125.

The opinion of investigators is divided concerning the origin of these calcified bodies. It appears that they do not always have the same origin. *Gottlieb* first called attention to the fact that the cementicles

FIG. 126
Enamel drop (b) in the bifurcation of a molar.
a. normal primary cementum.
c. cementum covering enamel drop, with enclosed epithelial cells.
d. dentin.

and cement exostosis are usually observed in the proximity of epithelial structures in the periodontal membrane. Many of these structures are the result of calcification of degenerated epithelial cells. Some-

times they result from other necrotic cells. If a connective tissue cell becomes necrotic it may calcify and

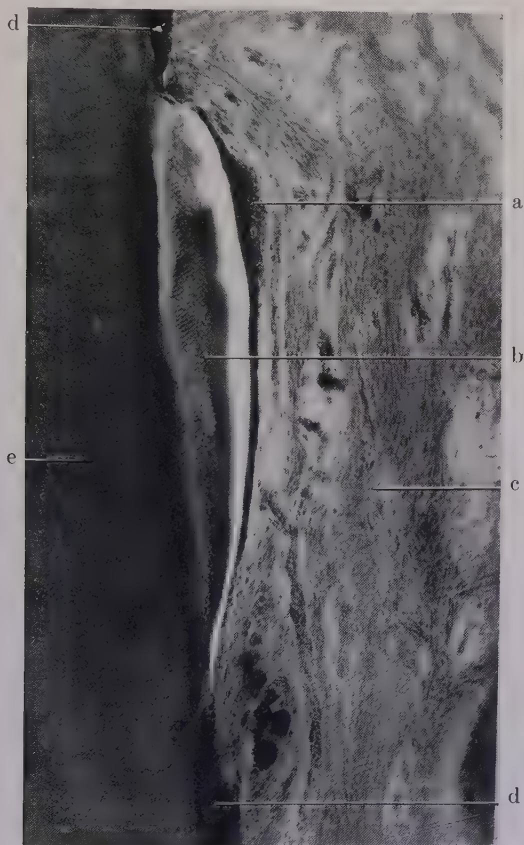


Fig. 127
Enamel drop (b) on the side of a molar.
a. enamel epithelium covering enamel drop.
c. periodontal membrane.
d. cementum. e. dentin.

serve as a nucleus for further calcification. It is also possible that calcified bodies may arise in the veins following thrombosis. However, the most common

origin of these cementicles seems to be the calcification of degenerated epithelial rests.

Enamel drops

Other structures very commonly found in teeth are the enamel drops. Enamel drops are found in places where

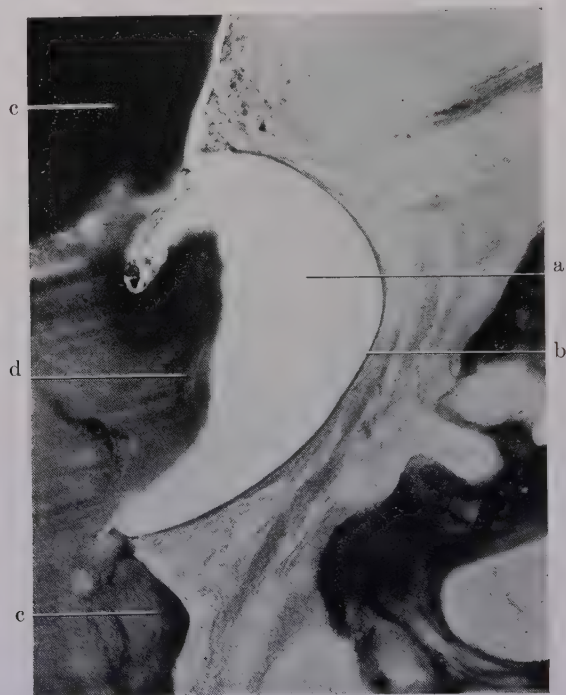


Fig. 128
Enamel drop (a) with dentin center (d) on the distal side of a third molar.
b. enamel epithelium.
c. cementum.

normally no enamel should be. Most commonly they are found at the bifurcation of multi-rooted teeth and on the outer surfaces of the roots close to the cemento-enamel junction. An enamel drop at the bifurcation of a molar is shown in Fig. 126. On one place the primary cementum appears to be lifted

from the surface of the dentin, and between the cementum and the dentin an enamel drop is located. Disturbances during root development may be the causes that lead to the formation of the enamel drops.

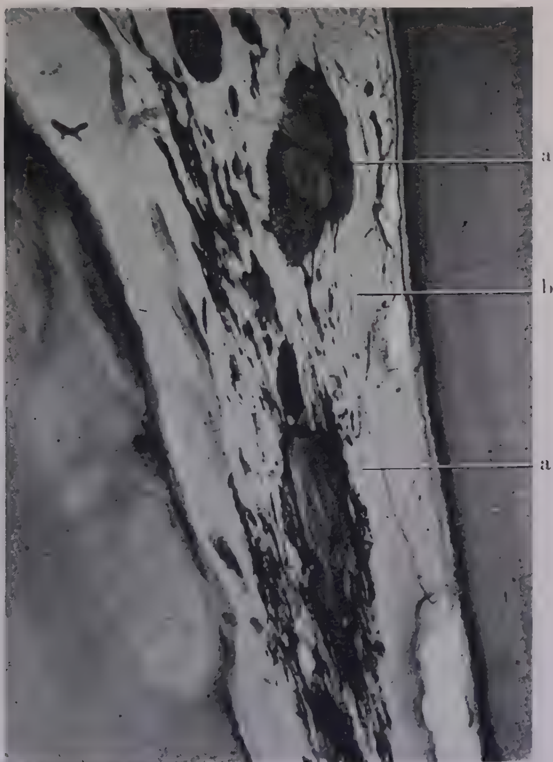


Fig. 129
Common calcification (a) in a pulp (b).

Hertwig's epithelial sheath, as previously described, is not a continuous covering of the developing root. The sheath is continuous only during development at the apex, on the sides of the roots it consists of torn away epithelial rests that are carried upward with the growing root. Sometimes the sheath may remain continuous for a

considerable distance and cover the root as shown in Fig. 127. This epithelium originates from *Hertwig's* epithelial sheath of the enamel organ, and when it remains continuous it may develop ganoblasts which then form the enamel drop. The difference between

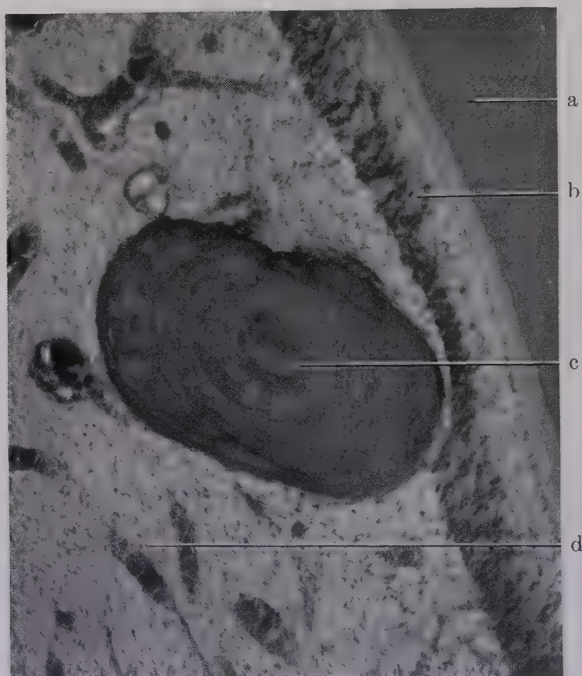


Fig. 130
False denticle (c) of concentric structure in a pulp (d).
a. dentin. b. odontoblasts.

the cases shown in the previous two Figures (126-127) is that the enamel drop in Fig. 126 is covered with cementum, and the other, (Fig. 127) is covered with epithelium. This epithelium is identical with the reduced enamel epithelium which covers the normal enamel before eruption. No cementum can be deposited on the enamel drops as long as they are covered

with epithelium. Generally this epithelium degenerates and breaks up. Both single and grouped epithelial cells are always found in the neighborhood of enamel drops. As breaks in the epithelium occur, connective

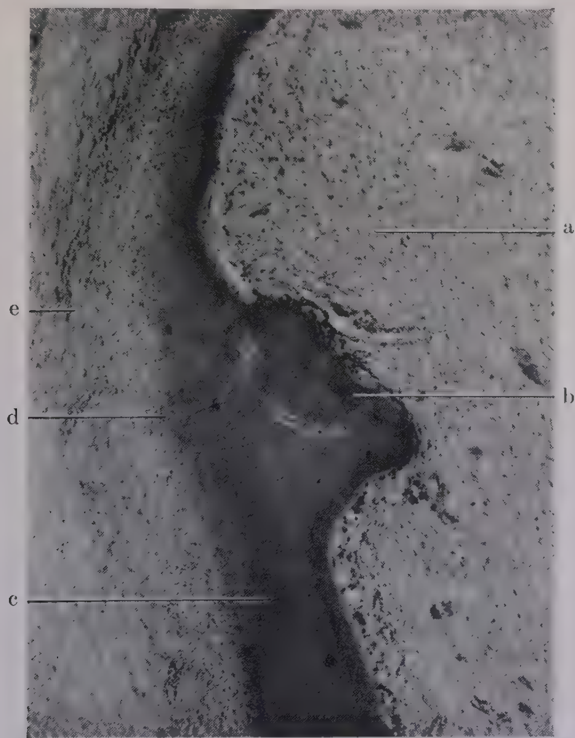


FIG. 131
True denticle (b) as a fold of the dentin wall (c).
a. pulp.
d. space leading into the denticle from the periodontal membrane (e).

tissue comes into contact with the surface of the enamel, and this connective tissue then forms the cementum. This cement covering of enamel drops has large cells enclosed in its matrix as illustrated in Fig. 126. These large cells are degenerated epithelial cells and are the

remains of the epithelial layer which built the enamel drop. Very frequently we find around enamel drops calcified bodies resembling cementicles. It seems

Fig. 132
True, free denticle (a).

that the epithelial cells in the periodontal membrane irritate the connective tissue, and result in the building of this type of cementum. Sometimes we find on the distal surfaces of the root of third molars enamel drops larger than are usually found. Such an enamel

drop is shown in Fig. 128. This enamel drop is not only made up of enamel but contains also dentin in its center. This in reality is not a true enamel drop,

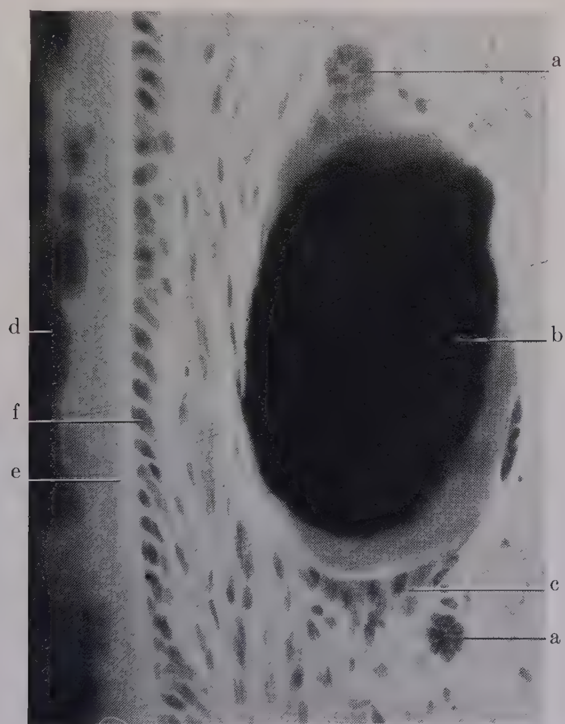


Fig. 133
Higher magnification of Fig. 132.
Denticle (b) with odontoblast (c). On both poles of the denticle epithelial rests may be noted. (a).
d. dentin.
e. new uncalcified dentin.
f. odontoblasts.

but more probably a mal-developed supernumerary tooth united with the third molar early in development. It was probably developed from the same toothgerm which formed the third molar.

Denticles

Denticles The description of denticles or so called pulpstones is taken up at this time, because in their origin they may have some connection with epithelial rests. Pulpstones are round-calcified bodies in the dental pulp. The causes which give rise to these structures are

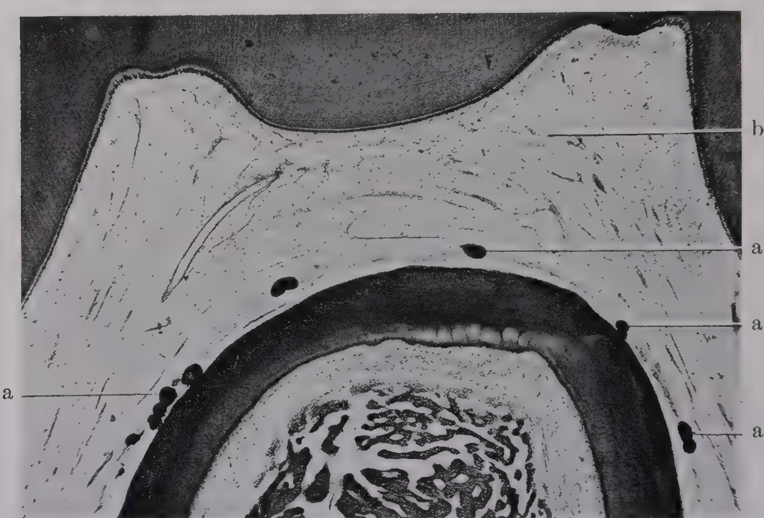


Fig. 134
Denticles (a) in the pulp (b) near the floor of the pulp chamber.

not well understood. Different types of denticles may result from different causes.

Common Calcifications *We classify the denticles as true denticles, false denticles, and common calcifications. The common calcifications* do not belong in the realm of normal histology for they *are the result of pathologic changes of the pulp.* Such a pathologic calcification is shown in Fig. 129. *False denticles are characterized by a matrix which resembles the matrix of the dentin, without dentinal tubuli and Tomes fibers.* Very often these false pulpstones show concentric arrangement as shown in Fig. 130 which

False denticles

points toward development from one center. Frequently we see a nucleus at this center. These false pulpstones may originate in the same manner as some of the cementicles. A pulp cell may become necrotic, then calcify, and around this center the pulp tissue may deposit the matrix of the denticle which later

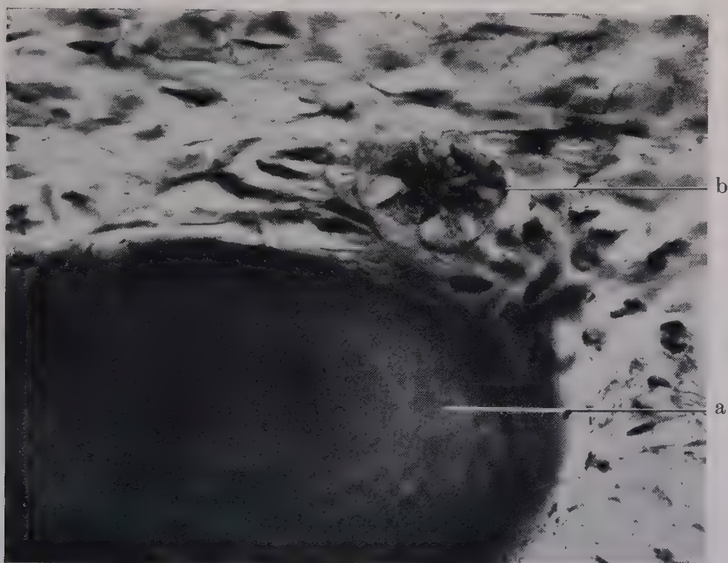


Fig. 135
Higher magnification of Fig. 134.
a. denticle.
b. degenerated epithelial rest.

calcifies. These pulp stones are probably of the same matrix as secondary dentin which frequently develops from fibers of the pulp without odontoblasts. *The false pulp stones, like the cementicles, may be free, adherent, and interstitial.* In the beginning they all develop freely in the pulp. The pulp chamber of young individuals is large, but becomes smaller with age. In this way denticles which were free in the pulp early in life later becomes adherent and finally interstitial.

True denticles

The well organized true denticles are characterized by the same structure as dentin. They are built by odontoblasts, have dentinal tubuli and Tomes fibers. As pre-

Fig. 136
Epithelial rests (a) in the pulp (c).
b. cementum lining the pulp canal.
d. resorption in the dentin.
e. cementum at apex.

viously described the enamel epithelium and *Hertwig's* epithelial sheath are necessary for the development of dentin. The epithelium probably stimulates the pulp cells to build dentin. No dentin can be built

without the presence of epithelium. This is the reason that true denticles develop only in conjunction with the epithelial sheath, either as folds in the normal

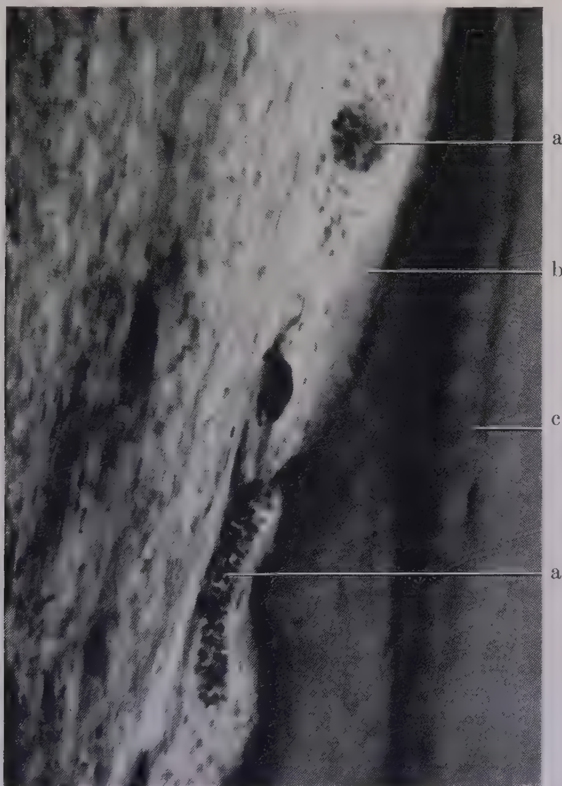


Fig. 137
Higher magnification of Fig. 136.
a. epithelial rests.
b. new cementum formation.
c. dentin.

odontoblast layer, as adherent denticles, or as free in the pulp. Fig. 131 shows a true denticle developed from a fold of the odontoblast layer. We can observe a space in the denticle coming from the periodontal

membrane. Originally the odontoblast layer followed the line which is now the outer surface of the dentin. We can imagine that a fold arose in the odontoblast layer (indicated now by the space in the denticle) and the dentin later developed corresponding to the folded odontoblasts. The result was an adherent denticle. It has been questioned whether true denticles can develop freely in the pulp or not. New findings may throw additional light on the subject. In Fig. 132 a free true denticle may be seen. Under high magnification Fig. 133 two epithelial rests may be observed in close proximity to the pulp stone. The presence of odontoblasts is evidence that this is a true denticle. The presence of the epithelial rests and the development of the true denticle appear to have a causal connection. Normally, epithelium is found on the outside of the dentin, as *Hertwig's* epithelial sheath. Occasionally epithelial rests are found in the pulp also, and it is reasonable to suppose that they will perform the same function in the pulp as they do at the end of the root during development—viz., to stimulate the pulp to build dentin. In the neighborhood of the epithelial rest the pulp cells become differentiated into odonto-blasts and build a true denticle. In Fig. 134 a case is presented with many pulp stones in an erupting tooth. Epithelial rests may be observed near the denticles. In a higher magnification of this specimen Fig. 135 epithelial rests may be seen showing signs of degeneration. The epithelial rests may disappear entirely from the pulp through this degeneration.

Epithelial rests in pulp with living Odontoblasts

Just how the epithelial rests come into the pulp may be explained by the diagram Fig. 120 which shows how the epithelial rests of the periodontal membrane arise. Cells from the end of *Hertwig's* epithelial sheath are carried along with the growing tooth. The same thing may happen at the pulp side of *Hertwig's* epithelial sheath. Epithelial cells may become separated

from the sheath, lodge in the pulp, and as the root grows, the separated epithelial cells are carried higher into the pulp.

Epithelial rests in pulp without Odontoblasts

Not infrequently we find epithelial rests in the pulp canal near the apex. Close examination shows the whole character of this tissue to be quite different from the usual pulp tissue, and also no odontoblasts are to be found. The cells of this tissue are not star-like as normal pulp cells, but are more elongated like common connective tissue cells. This is illustrated in Fig. 136. At e we see the apex built by cementum, at b cementum lines the inner wall of the dentin. Cementum is the product of connective tissue; no odontoblasts are to be seen. At d resorption has taken place. At a-a two epithelial rests are to be observed. A higher magnification of the epithelial rests is given in Fig. 137. It is not uncommon to find the odontoblasts degenerating in the apical region of the root canals, and the pulp tissue of this region replaced by connective tissue from the periodontal membrane. In most of the cases of adult individuals this is normal. Higher up in the same pulp chamber the odontoblasts may be found in a quite normal condition. However, in adult individuals a normal pulp with quite normal odontoblasts is seldom found. In pulp canals where the odontoblasts have disappeared, and common connective tissues is found in its place, we believe that it has originated from the connective tissue of the periodontal membrane. The epithelial rests in these cases may have been carried from the periodontal membrane into the pulp canal.

CHAPTER VI

ALVEOLAR BONE

The alveolar bone is formed by the connective tissue of the periodontal membrane as a result of the functional stimulus from the tooth. While the cementum is being deposited, the fibers of the periodontal membrane become embedded in it, and in this way transmit the

FIG. 138
Toothgerms of permanent biscupids and first molar. First deciduous molar in function. Compare the width of the periodontal membrane of IV and 5. 6 Toothgerm of first permanent molar.

Functional stimulus

force of the growing tooth to the surrounding bone. In consequence of this functional stimulus the connective tissue approximating the bone begins to lay down the alveolar bone. *Function in this case is not to be confused with the function of the tooth in mastication.* The functional stimulus of the growing tooth results from the movement of the developing tooth. Transmission of this functional force commences as

soon as cementum begins to be deposited and connective tissue fibers become embedded in it. Around toothgerms which have no cementum we observe a condensed area of bone known as the crypt of the

Bone crypt

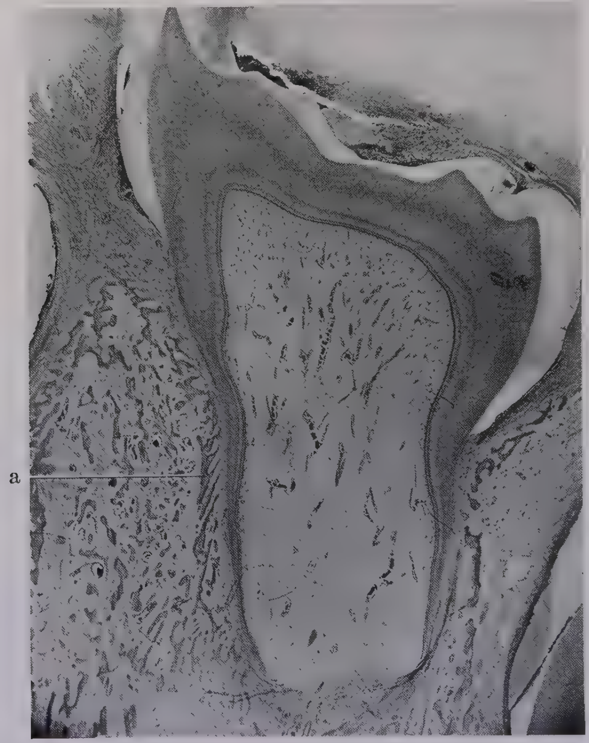


Fig. 139
Tooth with tip of one cusp erupted. At a bone trabeculae develop oriented in the direction of eruption.

follicle. This condensed bone is not a true alveolar bone; it is not developed as a result of functional stimulus. This type of condensed bone surrounds every larger space in spongy bone. We can see it around normal sinuses, also surrounding cysts and granulomas. Fig. 138 shows the crypts of toothgerms.

The periodontal membrane surrounding the toothgerm (5) compared with the periodontal membrane of an erupted tooth (IV) shows certain differences. The space surrounding the toothgerm is wider, and

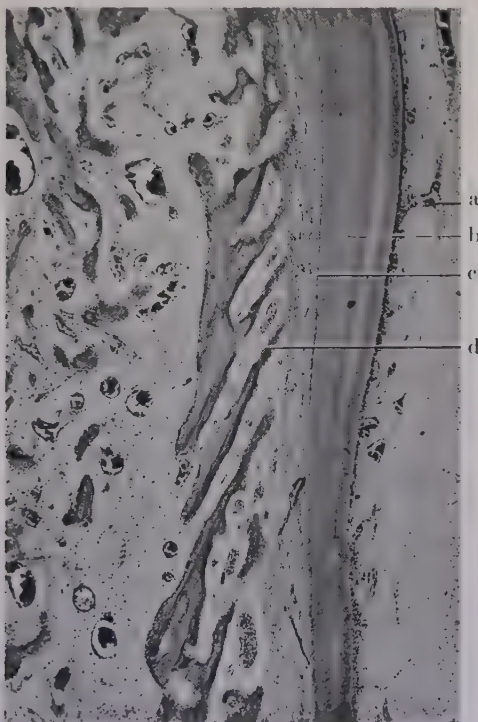


Fig. 140
Higher magnification of Fig. 139.
a. pulp. c. cementum.
b. dentin. d. "alveolar" bone development.

the fibers are differently arranged. As soon as the functional force becomes operative, new bone trabeculae develop. This is the beginning of the development of the proper alveolus. In Fig. 139 we see a tooth with the tip already erupted. The bone tra-

beculae of the surrounding bone have become oriented in the direction of the eruption. A higher magnification, Fig. 140, shows this more clearly. Cementum is also being deposited on the surface of the dentin.

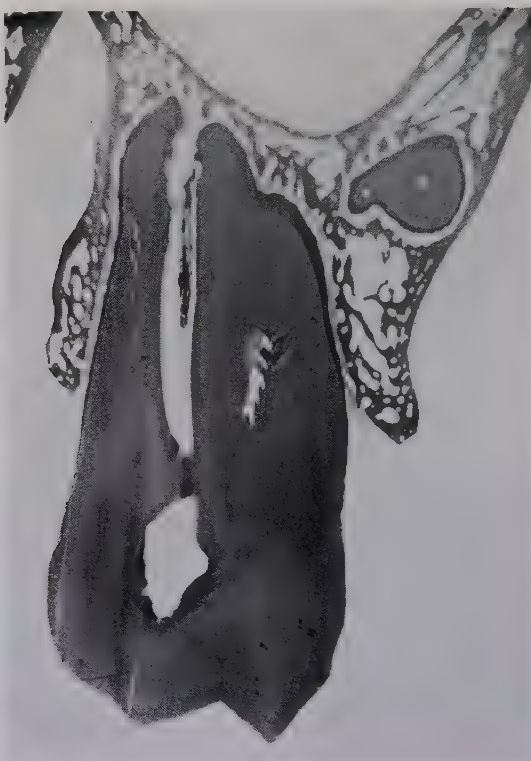


Fig. 141
Tooth in occlusion (left upper second molar) Normal "alveolar" bone and normal arrangement of the bone trabeculae of the "supporting" bone.

After the tooth reaches the line of occlusion, and begins its function of mastication, the bone trabeculae change their character in relation to this new function. It must be emphasized that the whole bone of the jaw

is not alveolar bone. *Only the inner layer of bone surrounding the root may be considered alveolar bone; the other bone adjacent to the alveolar bone is the bone of the jaw and supports the thin alveolar bone.* On the

Alveolar bone-Supporting bone

Fig. 142

Tooth (right upper second molar) from the same individual as Fig. 141. Without occlusion.

"Alveolar" bone normal, "supporting" bone trabeculae are resorbed and have disappeared.

labial and lingual surfaces, in some locations, the bone surrounding the teeth is very thin and consists largely of alveolar bone. This distinction between alveolar bone and supporting bone of the jaw is necessary

because of the difference in their function. The alveolar bone depends on the existence of the stimulus from the cementum. In the following two pictures we will attempt to explain the existence of alveolar

Fig. 143
"Alveolar" bone and "supporting" bone trabeculae.

and supporting bone. Both pictures originate from teeth of the same mouth and are the second upper molars from the right and left side. One tooth has been in normal occlusion, the other without occlusion.

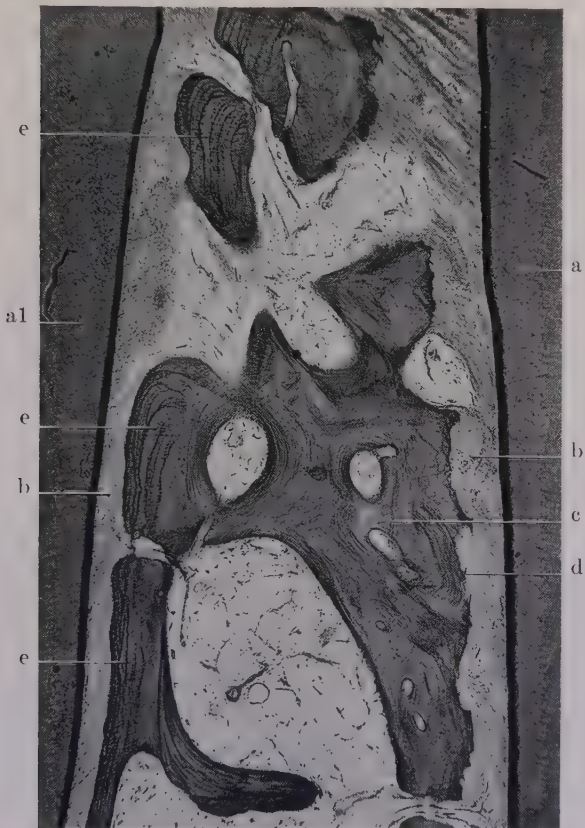


FIG. 144
Interdental septum between two bicuspids. The teeth are moving from the right to the left. The right side shows resorption of bone (d), the left apposition (e).

a. second bicuspid. c. lamellated bone.
a1. first bicuspid. e. bundle bone.
b. periodontal membrane.

Fig. 141 shows the left tooth in occlusion. The alveolar bone, the lamina dura is in normal condition, the supporting bone shows numerous bone trabeculae. Fig. 142 is the tooth without occlusion. We observe

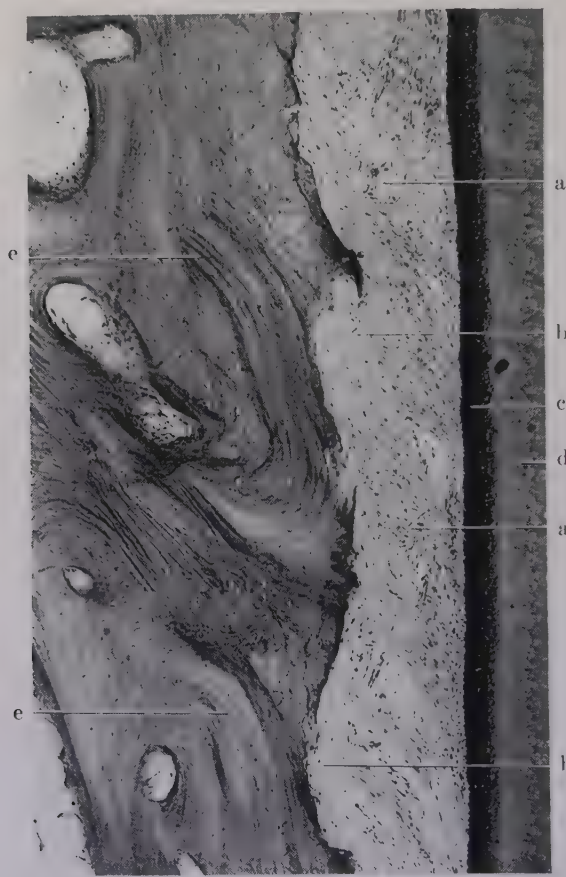


Fig. 145
Higher magnification of Fig. 144. Second bicuspid, mesial side.
a. periodontal membrane. c. cementum.
b. resorption of bone. d. dentin.
e. lamellated bone.

a normal almost uninterrupted "alveolar bone" around the root, but the supporting bone is very porous, has wide marrow spaces and only a few trabeculae. *It is important to note that the difference in function*

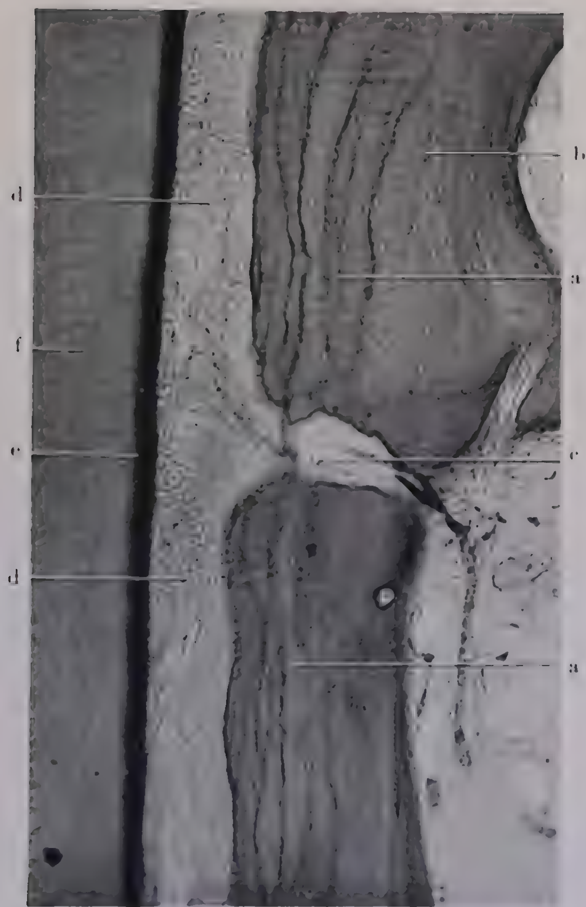


Fig. 146

Higher magnification of Fig. 144. First bicuspid, distal side.

a. bundle bone.
b. border between bundle and lamellated bone.
c. blood vessel running from marrow space to periodontal membrane.
d. periodontal membrane.
e. cementum.
f. dentin.

between the teeth from the two sides has resulted in differences in structure only in the supporting bone. The existence of the alveolar bone depends upon the condition of the cementum. Fig. 143 shows the arrangement of the bone trabeculae of the supporting bone, and the "alveolar bone."

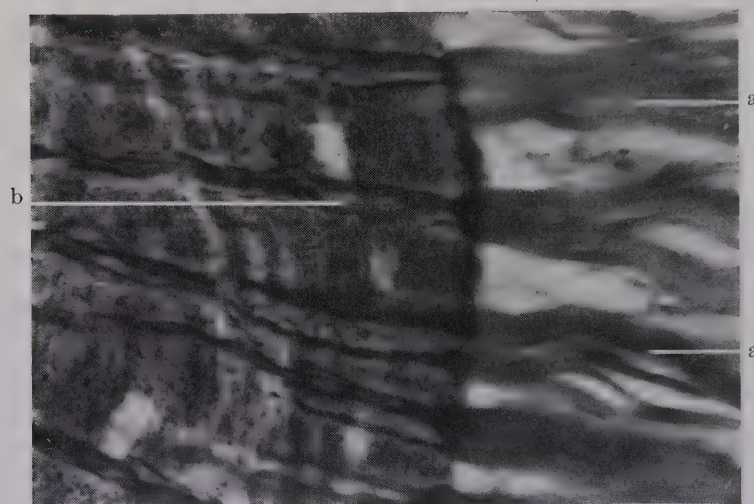


Fig. 147
High magnification of bundle bone.
a. fibers of periodontal membrane.
b. Sharpey fibers in the alveolar bone.

Weski called attention to the fact that the gingival tissues, cementum, periodontal membrane and alveolar bone are in a close functional connection with each other. He called this functional unit with one word "*paradentium*".

The recent investigations of *Stein* and *Weinmann* have given us a clear idea of the finer structure of the alveolar bone. It has been known for a long time that there are two types of bone in the jaw, the so-called lamellated bone, and bone which has more fibers embedded in it, the so-called "bundle bone." The

designation for this bone is bundle bone, for bundles of fibers become embedded in it. No attention was paid to the location of the two types of bone in the alveolus, the fact being taken for granted that there

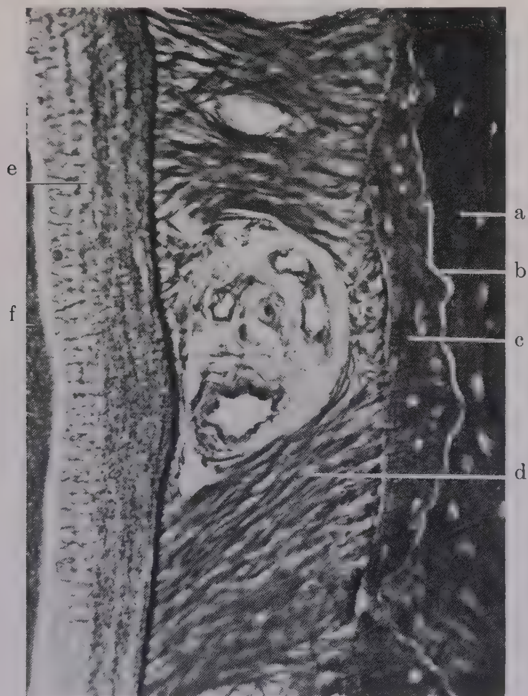


FIG. 148
Mesial side of alveolus.
a. lamellated bone.
b. resorption extended to this line, the lacunae are open toward the periodontal membrane (d).
c. new bundle bone. e. cementum. f. dentin.

were more fibers embedded in some parts of the alveolar bone than in other parts. We know from general histology that bone is formed from osteoblasts of connective tissue cells. It has a matrix composed of collagenous fibers embedded in a calcified cementing

Lamellated bone

substance. The collagenous fibers are connected with each other to small bundles and are arranged parallel to the bone lamellae. Osteoblasts become embedded in this matrix and give rise to bone corpuscles. Narrow

Fig. 149
Distal side of alveolus.
a. lamellated bone has replaced bundle bone (b) from the marrow spaces.
c. cementum.
d. dentin.
e. periodontal membrane.

lamellae of the bone are connected with each other in concentric or parallel layers, and these form the so-called lamellous bone. The lamellae for the most part are circular, and run around canals called the *Haver-*

sian canals. The bundle bone is built by the same structural elements, but has embedded in its matrix groups of fibers extending from the bordering connective tissue. These fibers running from the connective tissue into the bone are the so-called *Sharpey's* decussating fibers. *Stein and Weinmann* have shown that *the distribution of the two types of bone in the alveolar process depends upon the movement of the teeth.* It is a well-known fact that *the teeth* in occlusion are not stationary, that they *move physiologically in the direction of the middle line.* This movement of the teeth is probably due to the natural wearing of the contact points to contact planes. The arch of the jaw remains almost the same and the teeth maintain contact; this is possible only if the teeth all move in the direction of the mid line. The alveolar bone is different in character on the tension (distal) side compared with the pressure (mesial) side due to this physiologic movement. The teeth move toward the mesial side and exert pressure on the mesial alveolar bone. This pressure causes a resorption of the lamellated bone. At the same time the fibers embedded in the cementum and bone on the distal side of the alveolus become stretched. They transmit the stimulus to the surface of the bone, and new bone is laid down. The fibers become more and more embedded in the bone which results in bundle bone. Fig. 144 shows the interdental septum between two bicuspids. On the right side of the picture the limit between alveolar bone and periodontal membrane is a broken line, bordering lacunae. On the left side the alveolar bone is more regular and shows no lacunae, but embedded Sharpey fibers. From this structure of the bone we conclude that the teeth move from the right side toward the left. Fig. 145 is a higher magnification of the right side of Fig. 144, where resorption has taken place. The alveolar bone is of the lamellated type, having no Sharpey fibers embedded in its matrix.

Bundle bone

Physiologic movement of the teeth

The tooth moves toward this bone. Fig. 146 is a higher magnification of the left side of Fig. 144. The embedding of Sharpey's fibers in the matrix of the new aveolar bone indicates that the tooth moves in the direction away from this bone. In Fig. 147 the Sharpey

Fig. 150
Epithelial rests (c) under the apex of a tooth (a).
b. floor of alveolus.

fibers are shown in a specimen impregnated with silver. Not single fibers only, but bundles of them run from the periodontal membrane into the bone. *As a rule we can say that the mesial side of the alveolar bone is formed by lamellated bone, the distal side by bundle bone.* The physiologic wandering is often dis-

turbed by malocclusion or extraction of the teeth in which cases teeth wandering in different directions can be observed, and so the structure of bone varies. It is also stated that the physiologic wandering of the teeth occurs periodically; it stops for a time and then proceeds again. For this reason we sometimes observe bundle bone deposited in places where the lamellated bone has been resorbed on the mesial surface, as is shown in Fig. 148. The wandering in this case had stopped. We observe the resorption lacumae toward the periodontal membrane, and that bone was deposited in which fibers of the periodontal membrane were embedded. When the wandering again takes place this bundle bone becomes resorbed. The bundle bone does not remain long in places in which it has no special function, such as to keep Sharpey's fibers embedded. The portion of the bundle bone lying closest to the marrow spaces become gradually resorbed and replaced by lamellated bone. The resorption lacunae are concave toward the marrow spaces, (Fig. 149), indicating that the resorption came from these spaces. The resorbed bundle bone is replaced by lamellated bone according to the architectural requirements of the jaw.

The physiologic movement of the teeth not only takes place toward the median line but also toward the occlusal line; that is, the teeth actually become longer. As mentioned previously, the epithelial attachment grows gradually deeper along the cementum. This epithelial downward growth might lead us to think that no actual wandering of the tooth out of the alveolus had taken place but only an epithelial downward growth. The occurrence of bundle bone at the apical region of teeth indicates that actual outward growth does take place. This, however, is not the only proof that the teeth move in the direction of the occlusal line.

It has been stressed that the epithelial sheath of *Hertwig* is present at the end of the root during its

Epithelial rests under the apex

whole development. The epithelial remains of *Hertwig's* sheath, the epithelial rests after the root is built are found in close proximity to the apex. If epithelial rests are found deep in the channel through which

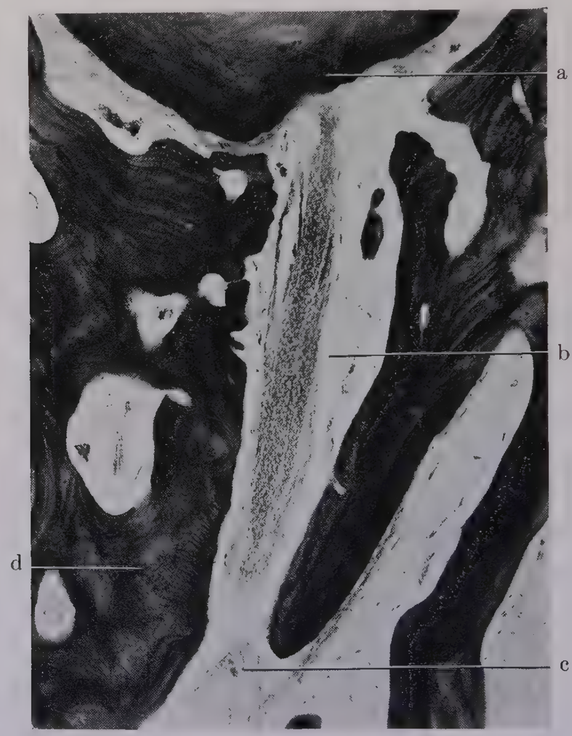


Fig. 151
Epithelial rests (c) and bundle bone (d) distant from the apex (a).
b. canal carrying nerve and blood vessels to the pulp.

blood vessels and nerves reach the pulp, one conclusion only is possible, and that is, that the apex of the tooth must have been at one time in this region. This is shown in Fig. 150. The same behavior is to be observed in Fig. 151. Two epithelial rests are found

lying about 3 mm. from the apex. Not only the epithelial rests indicate the wandering of the teeth in this case, but as can be seen in higher magnification (Fig. 152) bundle bone still remained embedded in the

Fig. 152
Higher magnification of Fig. 151. (c-d)
a. canal for nerve fibers and blood vessels.
b. epithelial rests.
c. bundle bone.

lamellated bone close to the epithelial rests. Both the presence of the bundle bone and the epithelial rests are indications that the apex of the tooth once occupied this region.

CHAPTER VII

SHEDDING OF THE TEMPORARY TEETH

There is no remarkable difference between the structures of the deciduous and permanent teeth. The epithelial attachment is similar in both, also the downward growth of the epithelium along the cementum

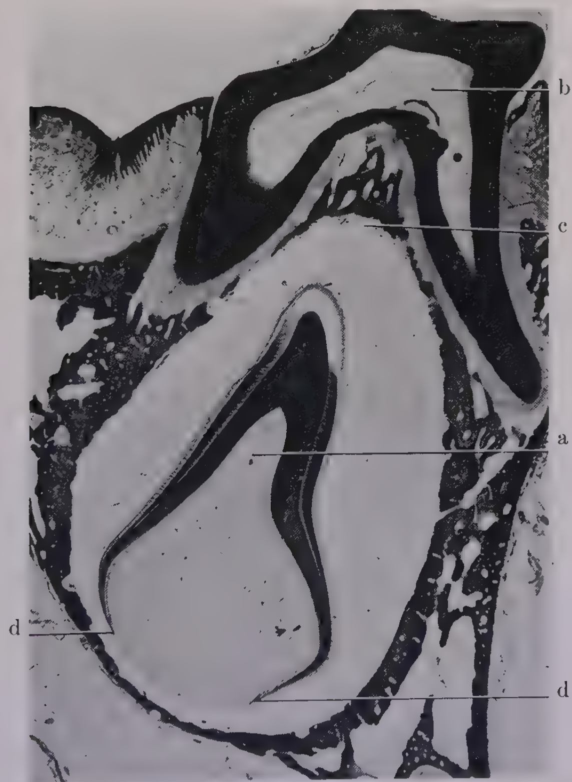


Fig. 153
Permanent toothgerm (a) surrounded by bone.
b. deciduous tooth.
c. resorption of bone.
d. Hertwig's epithelial sheath.

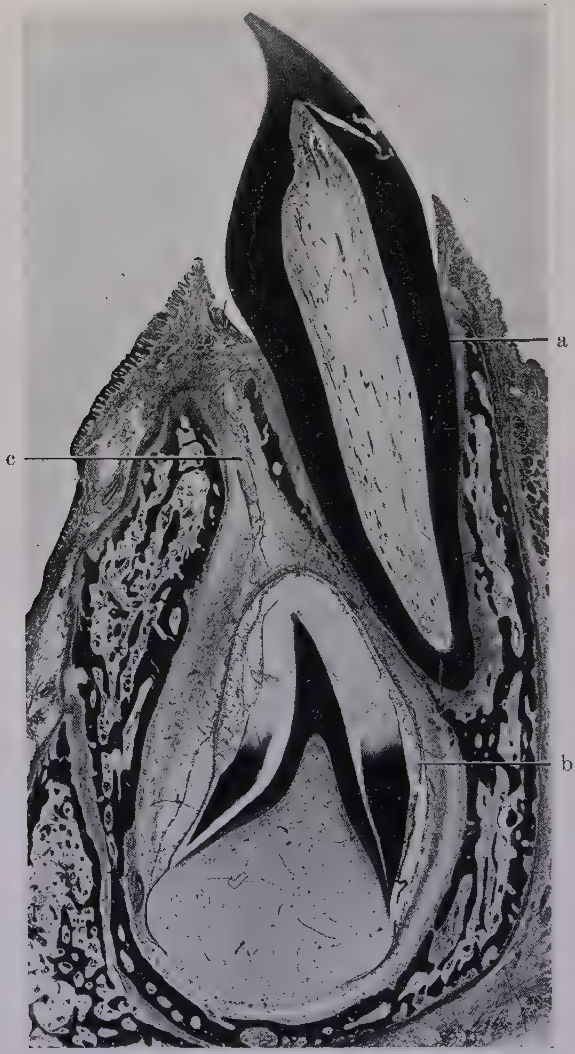


Fig. 154
Permanent toothgerm (b).
a. deciduous tooth.
c. canal with remnant of epithelial dental lamina.

occurs in the same manner. Bundle bone is also found in the alveolar bone of deciduous teeth; the periodontal membrane is the same in structure.

The toothgerms of the permanent teeth are found in a bone crypt, and through this surrounding bone they are separated from the deciduous teeth. This can be observed in Fig. 153. However, the bone crypt is not entirely closed around the whole toothgerm, but as illustrated in Fig. 154 is open toward the mucuous membrane of the mouth. This leads from the toothgerm to the surface epithelium. The dental lamina was connected with the toothgerm through this channel, now epithelial rests only are found as remainders of the former dental lamina. In the case of single-rooted teeth (Fig. 154) the permanent toothgerms are located lingually from the roots of deciduous teeth, and between the roots in the case of multirooted teeth, (Fig. 153).

Resorption of bone and root

At the time the permanent teeth begin to grow and erupt, the bone and deciduous teeth overlying the tip of the erupting tooth become resorbed to make room for the growing permanent teeth. In Fig. 153 we observe resorption of the inner wall of the bone crypt. Resorption of the root of the deciduous tooth has not yet begun. Not all of the bone between the permanent toothgerm and deciduous tooth needs to be resorbed before resorption of the root begins.

The resorption of the bone and deciduous root is due to pressure from the growing toothgerm. This pressure is due not only to the growing of the toothgerm but also to an hyperemia of the connective tissue surrounding the toothgerm. As a result of the increased pressure ostoclasts appear and these resorb the hard substances. This resorption prepares the way for the growing toothgerm.

Fig. 155 illustrates a case where the root of the deciduous tooth is well destroyed, on one side of the root the pulp canal is opened. Under physiologic

conditions the enamel of the permanent toothgerm never comes in direct contact with bone or root because the enamel is covered with enamel epithelium. Between enamel epithelium and bone or root of the deciduous tooth we find connective tissue. This connective tissue brings about the resorption. The enamel epi-

Fig. 155

Deciduous tooth (b). At (c) the root is resorbed leaving the pulp canal open.

a. hemorrhage in the periodontal membrane.
d. enamel of permanent tooth.
e. dentin of permanent tooth.

thelium serves a protective function in addition to its regular function of building of the enamel.

The pressure resulting from the growing toothgerm is exerted not only in the direction of the bone or root of the deciduous tooth but also in the direction of the growing toothgerm. If the surface of the enamel is not protected from the action of the connective

tissue by the epithelium, it also may become resorbed.
As the resorption of the roots of the deciduous teeth progresses, the teeth become more and more functionless. Large areas of the periodontal membrane

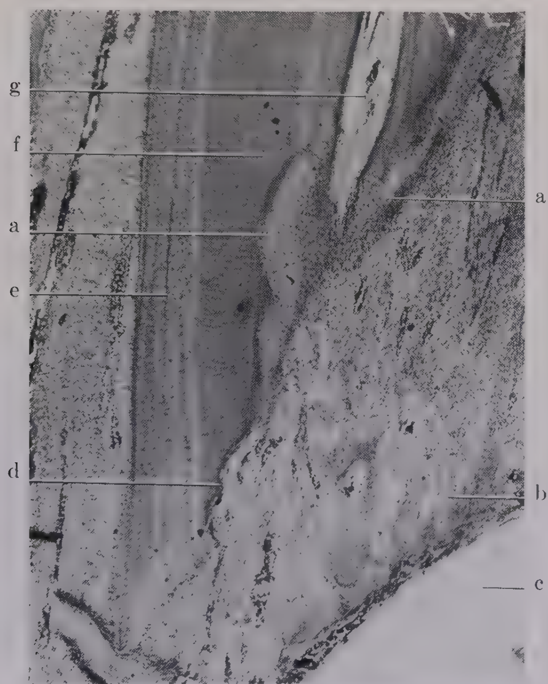


Fig. 156
Root end of deciduous tooth.
a. new bone deposited on the surface of the resorbed root.
b. new bone trabeculae built between deciduous root and permanent toothgerm (c).
d. resorption. e. cementum. f. dentin.
g. root canal of deciduous root.

are destroyed; as a result the remaining periodontal membrane becomes strained and not infrequently damaged. In almost all cases of resorbing deciduous teeth, we find hemorrhages and necrotic areas as a

result of damage done to the supporting apparatus. Further changes usually accompanying the shedding of deciduous teeth are illustrated in Fig. 155. In this illustration new bone trabeculae are found at places where the cementum and dentin were resorbed. This new building of bone is to be seen in almost every specimen of tooth shedding. *Oppenheim* has pointed out that *the resorption and new building of bone are indications of an intermittent process. The growth and eruption of the teeth is not a continuous process but an intermittent one.* During the growth period of the permanent tooth the bone and deciduous roots become resorbed. Due to pressure and hyperemia from the growing tooth more bone and deciduous tooth substance become resorbed than what is immediately required to give place to the developing tooth. Growth stops, and the pressure subsides, then new bone is deposited in the resorbed area. Fig. 156 illustrates this process. It is the end of a root of a deciduous tooth. The dentin as well as the cementum has been resorbed. New cementum on the resorbed surface is an indication that the growth has stopped. New bone trabeculae are formed between the root of the deciduous toothgerm and enamel organ of the permanent toothgerm.

Resorption and deposition alternate. However, more resorption than new building always takes place. Ultimately the resorption wins out in this alternating cycle, and finally the deciduous teeth are cast off and the permanent teeth erupt in their places.

CHAPTER VIII

DEVELOPMENT OF THE TEETH

The teeth as described in the previous chapters are built from different types of tissues. The dentin and the cementum are derived from connective tissue, the enamel from epithelium which originates from the stratified squamous epithelium of the mouth.

The first sign of tooth development is a thickening

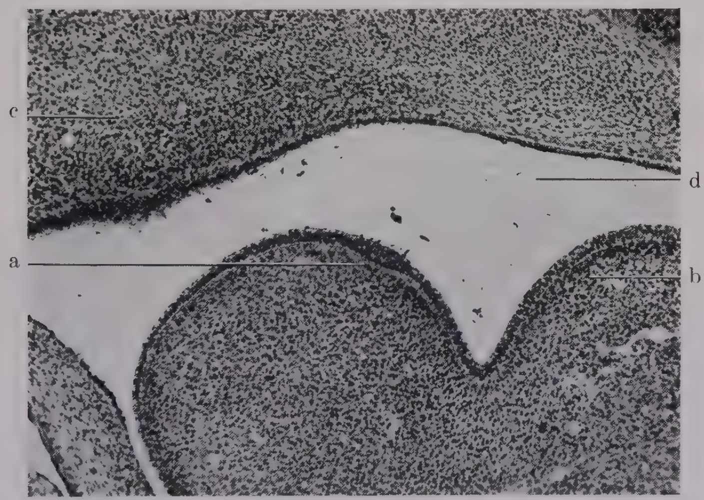


Fig. 157
Thickening of mouth epithelium (a) of the lower jaw of a 13.44 mm. human embryo (38-40 days) sectioned labio-lingually.
b. tongue. c. upper jaw. d. mouth cavity.

of the mouth epithelium at certain places. This occurs between the 34-38th day of embryonic life. The size of the embryo at this time is from 11-13 mm. in total length.

In Fig. 157 a region of the mouth cavity of a 13.44 mm. long human embryo[1] shows *the first sign of tooth development.* At this stage of development there is

First sign of tooth development

[1]All illustrations used in this chapter originate from human specimens.

only a slight differentiation between the organs of the embryo. The tongue and the future jaw are separated only by a slight groove. In the lower jaw there is a point where the epithelial layer is thickened. This is the place where the tooth will later develop, and is

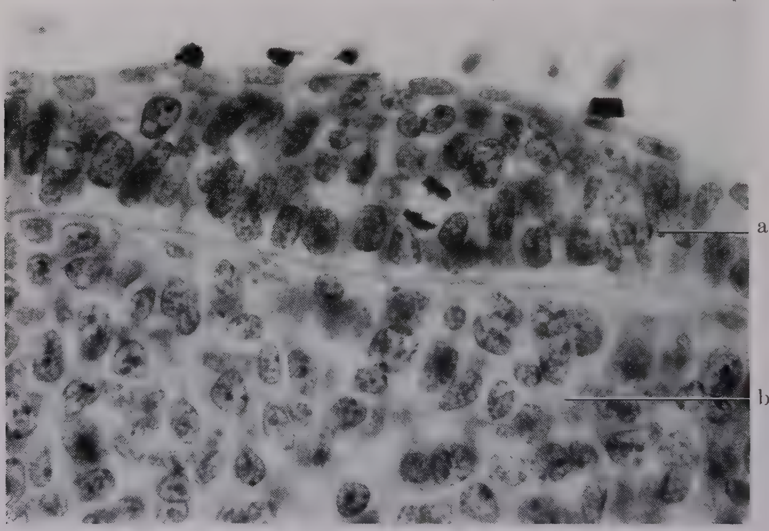


FIG. 158
Higher magnification of region a from Fig. 157.
a. epithelium with cell division.
b. connective tissue.

called *the dental anlage*. A higher magnification of this thickened part is shown in Fig. 158. Cell division is to be observed in this part of the epithelium. The epithelium is separated from the connective tissue by a membrane—the so-called *membrana limitans* (Basal membrane). Cell divisions not only may be seen in the epithelium, but at several places in the adjacent connective tissue as illustrated in the next photograph, Fig. 159. This photograph was made from a neighboring section of the same series.

The study of the cell divisions demonstrates that *the conception* generally accepted *that the epithelium of the mouth grows down into the connective tissue to build the tooth is not correct. There is not only growth of the epithelium but also of the surrounding tissue. There is no active epithelial downward growth.* I have made measurements of the toothgerms of human embryos varying in length from 16 mm. to 217 mm.

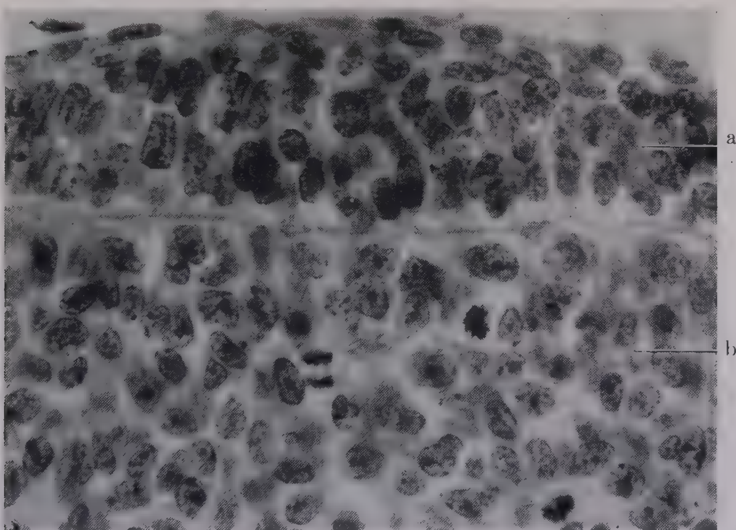


FIG. 159
Same specimen as Fig. 158, neighboring section.
a. epithelium.
b. connective tissue with cell divisions.

The measurements comprised: the distance from the floor of the nose to the toothgerm (a), the length of the toothgerm (b), and the distance of the toothgerm to the mouth epithelium (c) as shown in diagram Fig. 160. The results obtained from these measurements are given in Fig. 161. The length of "a" viz. the distance from the floor of the nose to the tooth-

germ is shortest in the smallest embryo; it becomes slightly longer in the course of development. The greatest increase takes place in "b" and "c". This shows that *the epithelium of the mouth does not grow into the connective tissue in order to build up the dental lamina and the toothgerms, but certain parts of the mouth*

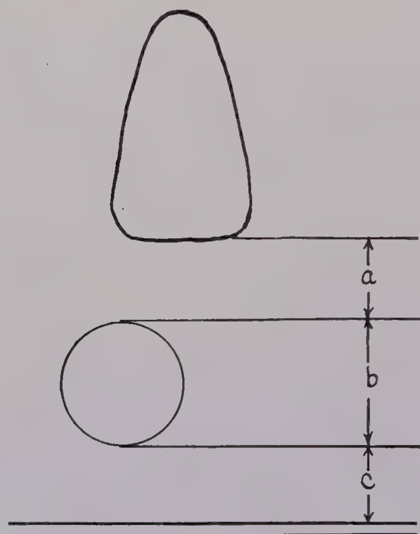


FIG. 160
Diagram showing plan of measurements.
a. distance between floor of nose and deepest point of tooth germ.
b. length of toothgerm.
c. distance between toothgerm and mouth epithelium.

epithelium remain at their original places while the surrounding tissues grow. Of course there is some growth also in the epithelium of the dental lamina and in the toothgerms, but this is not an active growth but a growth synchronous with that of the surrounding tissues.

In the following diagram Fig. 162 this conception

will be further explained. In the upper part is illustrated the old idea of tooth development. In the beginning the dental lamina is short and becomes longer during the course of development. The distance "a" increases. After the dental lamina has attained a certain length the toothgerms develop. My conception is shown in the lower diagram. Models of the toothgerms show that the toothgerms do not

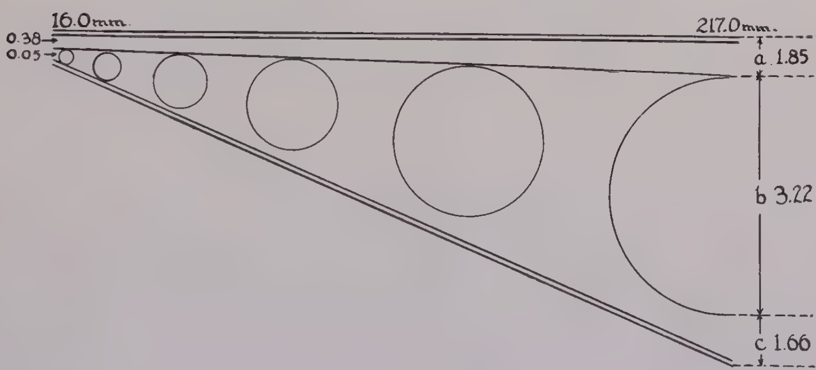


Fig. 161
Diagram showing the results of measurements.
Distance (a) 0.38 mm. in a 16 mm. embryo; 1.85 mm. in a 217 mm. embryo. Increase—5 times.
Distance (b-c) 0.05 mm. in a 16 mm. embryo; 4.88 mm. in a 217 mm. embryo. Increase—100 times.

develop after the dental lamina has partially formed, but that they develop simultaneously with the dental lamina, while the surrounding tissues grow centrifugally. The effect of this growth increases the distance between the floor of the nose and the mouth epithelium. The distance between the toothgerm and the floor of the nose remains practically the same.

The dental anlage of a 16 mm. human embryo (about 46 days) is shown in Fig. 163. The thickening of the epithelium is more pronounced, than in the 13.44 mm. embryo. The dental anlage does not extend quite at right angles from the mouth epithelium into

the connective tissue, but is inclined slightly toward the lingual. A higher magnification, Fig. 164 shows the thickened area of the epithelium of the lower jaw.

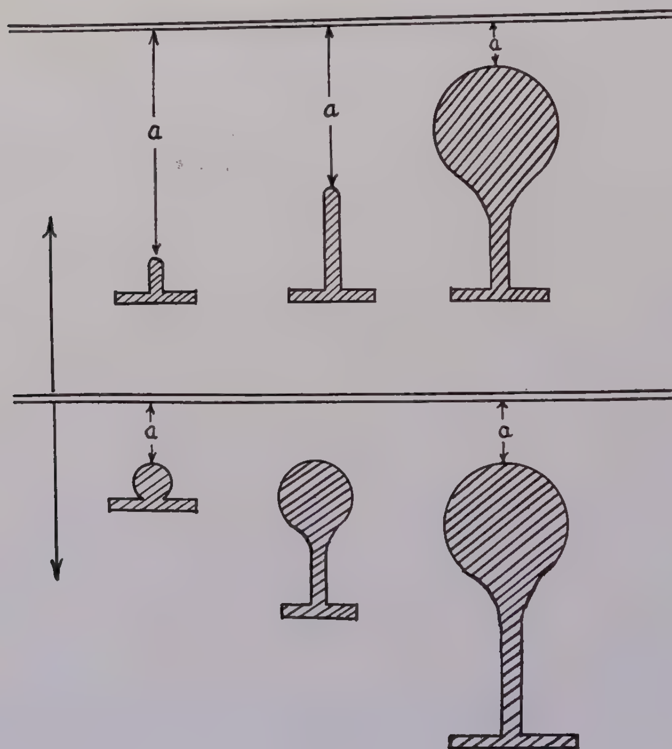


FIG. 162

Diagram showing old and new conception of tooth development.

Upper diagram shows the old conception; the dental lamina becomes progressively longer and when it reaches a certain length, the toothgerm develops.

Lower diagram shows the new conception; the toothgerm develops simultaneously with the dental lamina. Growth proceeds centrifugally and not centripetally.

Cell divisions in the connective tissue and epithelium are numerous. In the mouth epithelium labially from the dental anlage a somewhat thickened area is seen.

This, I believe, forms the labio-dental lamina or the so-called *lip furrow band. The dental anlage in Fig. 163 is not only a dental lamina but already a toothgerm.* Dental lamina and toothgerms develop simultaneously; the dental lamina does not precede the toothgerms.

First sign of lip furrow band

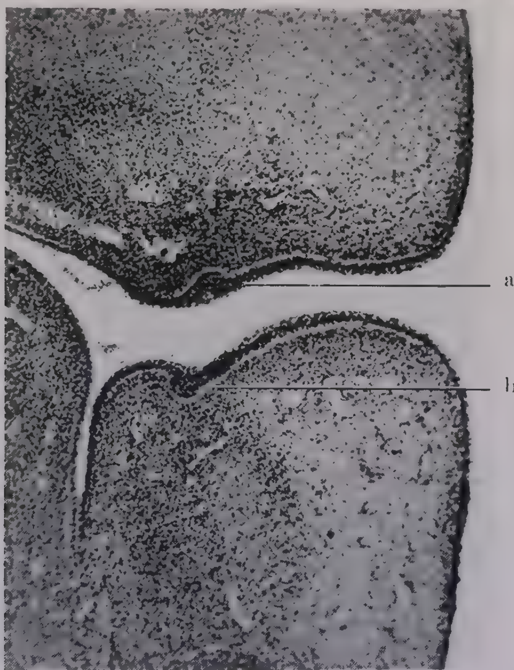


Fig. 163
Dental anlage of a 16 mm. human embryo (about 46 days). Sectioned labio-lingually.
a. dental anlage in the upper jaw.
b. dental anlage in the lower jaw.

A model of two lower incisors of the 16 mm. embryo is shown in Fig. 165. The model gives us a view of the toothgerms from below. This model is made from the same series of sections from which Fig. 163 and 164 were made. Elevations on the mouth epithelium

may be observed on the model. These are the anlagen of two teeth.

Method of making the models

The method of making the model shall be described. The embryos are sectioned in unbroken series, the sections being of the same thickness; for example, 20 micra. The image of *each section* enlarged, for example 200 times, is projected from a microscope

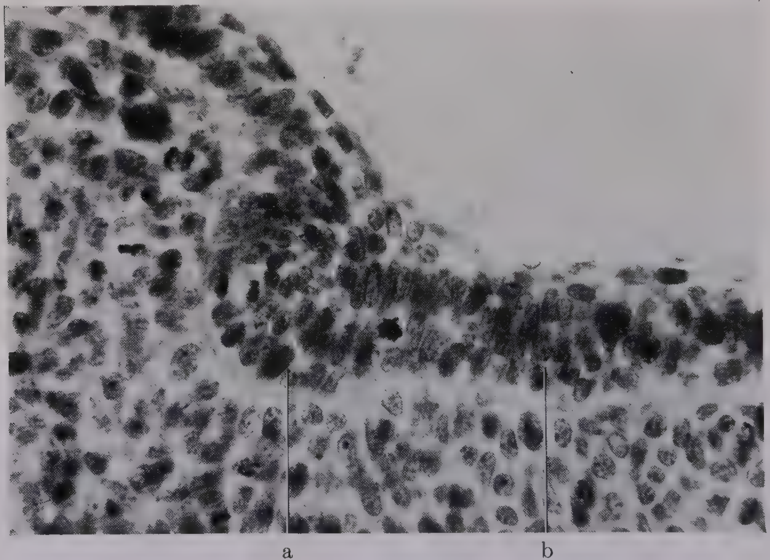


FIG. 164
Higher magnification of lower dental anlage (a) of the lower jaw of Fig. 163. Cell divisions in the epithelium and connective tissue.
b. first appearance of the lip furrow band.

on to a table. The outline of the projected image is traced on paper. Wax is poured on the paper to a depth of 4 mm. The thickness of the wax plates is obtained by multiplying the thickness of the section (20 micra) by the enlargement factor (200)—4 mm. The outline of each drawing is carefully cut in the wax plates and the plates piled up serially in the same order as the sections were cut. In this way is obtained

a wax model of the natural shape of the structures. All the models used as illustrations show the tooth anlagen of the lower central and lateral incisors of human embryos, a part of the epithelium of the lip, and the floor of the mouth.

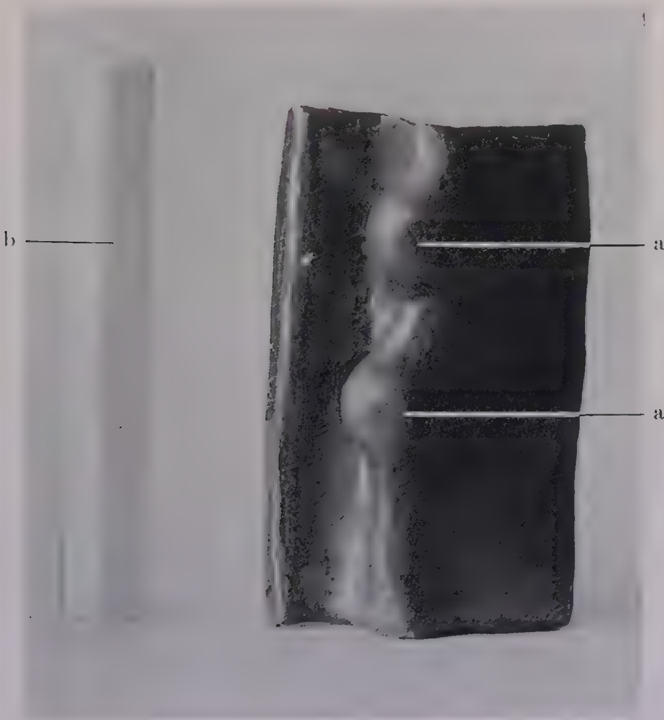


Fig. 165
Model of the tooth anlage of the central (a) and lateral (a') lower incisor of a 16 mm. embryo. (Fig. 163-164).
b. measure 10 cm. long.

A tooth anlage from a 20.0 mm. embryo (50 days) is shown in Fig. 166. The development is more advanced, the anlage is longer and is pear-shaped. The lip furrow band is definitely marked labially from the dental lamina.

From these photographs we conclude that *the dental lamina and toothgerms are built separately from the lip furrow band.* Both structures develop independently—the toothgerm a little in advance of the lip

FIG. 166
Tooth anlage of a 20.0 mm. human embryo. (about 50 days). Sectioned labio-lingually.
a. upper jaw.
b. lip furrow band.
c. dental anlage in the lower jaw.
d. tongue.

furrow band. We can not speak of a primitive dental lamina which divides later in two parts, the dental lamina and the lip furrow band. Both of them arise separately from the mouth epithelium, but it appears as though they originated from the same place, and

that the dental lamina has developed at right angles from the lip furrow band. Models of early development contradict the conception that the toothgerms and the lip furrow band arise from a common point. In the beginning the rate of development of the toothgerms is faster than that of the lip furrow band.

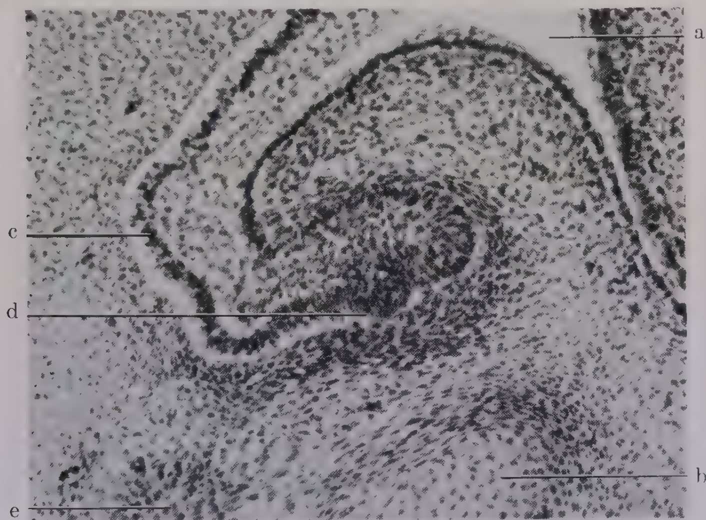


Fig. 167
Toothgerm of a 23.44 mm. human embryo. (lower central incisor). Sectioned labio-lingually.
a. mouth cavity.
b. Meckel's cartilage.
c. lip furrow band.
d. enamel knot.
e. bone.

A photomicrograph of a toothgerm from a 23.44 mm. embryo is shown in Fig. 167. The development is further advanced. The lip furrow band is still very shallow. The elevation seen in the middle of the toothgerm is described by *Arhens* as an "*enamel knot.*" The cells are more condensed in this area than in any other part of the toothgerm. The significance of this structure is still debated,—it disappears later. The *Enamel knot*

model shown in Fig. 168 is constructed from the series of sections from which Fig. 167 was obtained. The toothgerms in this model compared with the section is viewed from the side of *Meckel's* cartilage. The

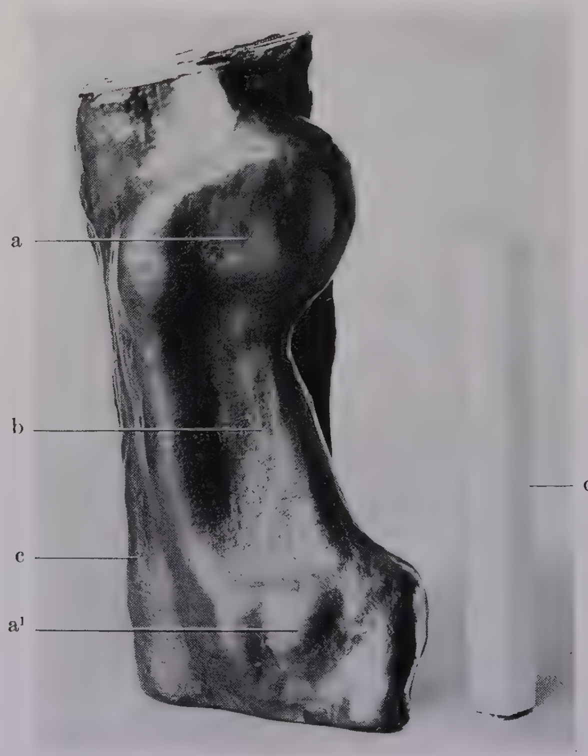


Fig. 168
Model of lower central and lateral incisors of a 23.44 mm. human embryo.
a. central incisor. b. dental lamina.
a¹. lateral incisor. c. lip furrow band.
d. measure 10 cm. long.

model shows a slight depression between the lip furrow band and the toothgerm. The enamel knot is well developed in both toothgerms. Fig. 167 shows a difference between the epithelium of the lip and floor

of the mouth. The epithelium of the floor of the mouth is very thin; it consists only of the stratum germin-

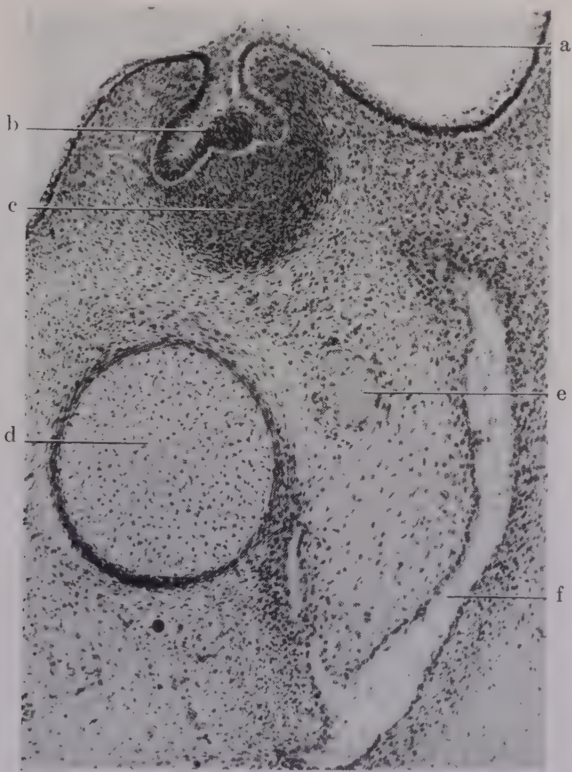


Fig. 169
Toothgerm of a lower first molar of a 24.0 mm. human embryo. Sectioned labio-lingually.
a. mouth cavity.
b. toothgerm—enamel knot.
c. condensation of connective tissue around toothgerm.
d. Meckel's cartilage.
e. mandibular nerve.
f. jaw bone.

ativum and one or two layers of cells. The epithelium toward the labial consists of the stratum germinativum

covered with more layers of cuboidal and round cells. This difference in the thickness of the epithelium already exists in the 16 mm. stage. (Fig. 163.) The connective tissue around the toothgerm is condensed, and *Meckel's* cartilage and bone formation are in

FIG. 170
Toothgerm of the lower lateral incisor of a 31.4 mm. human embryo (about 62 days) Sectioned labio-lingually.

a. tongue.
b. mouth cavity.
c. epithelium extending to lip.
d. lip furrow band.
e. enamel knot.
f. jaw bone.

evidence. Bone formation begins in the lower jaw in the 16 mm. embryo. *Meckel's* cartilage is believed to be the primitive jaw which precedes bone building. However, bone is not built by transformation of *Meckel's cartilage* Meckel's cartilage, but is laid down as membranous bone on the surface of the cartilage and replaces the resorbed cartilage. In Fig. 169 the toothgerm of the lower first molar[1] of a 24.0 mm. human embryo is

[1]*All photographs unless otherwise indicated are taken from toothgerms of deciduous teeth.*

shown. The enamel knot, and condensation of connective tissue around the epithelium is evident. At the side of *Meckel's* cartilage, quite separate from it, the bone of the jaw is formed in a V-shape. The nerve bundle is the future nervus mandibularis. From my observation there is no appreciable difference in the gross development of incisors and molars.

Fig. 170 is a section through the middle of the toothgerm of a lower central incisor of a 31.4 mm. human embryo (62 days). Fig. 171 shows the model of the lower central and lateral incisor of the same embryo, and is viewed from the side of *Meckel's* cartilage. The distinction between the toothgerm, dental lamina, and lip furrow band is now apparent. The toothgerm is now further removed from the mouth epithelium. I emphasize the fact that the epithelium of the mouth and the toothgerms do not grow into the depths. The elongation of the dental lamina is not due to an extension of the epithelium downwards. *The deepest point of a toothgerm is the relatively fixed point in the development.* The toothgerms grow in every direction, there is a synchronous growth in the surrounding tissues and therefore the distance from the deepest point of the toothgerm to the mouth epithelium becomes longer; yet the deepest point of the toothgerm in relation to surrounding structures, as for instance, the floor of the nose or *Meckel's* cartilage, remains relatively the same. To illustrate figuratively we may compare the toothgerm with a rubber band fixed at one end and pulled at the other. The fixed point corresponds to the deepest point of the toothgerm, the pulled end to the mouth epithelium. In this comparison the main difference is that the rubber band becomes thinner when pulled; the toothgerm and dental lamina become thicker during development. The growth and elongation of the toothgerm is not a passive process.

The photograph in Fig. 170 shows the enamel knot

and the condensation of connective tissue around the toothgerm. The difference between the epithelium of

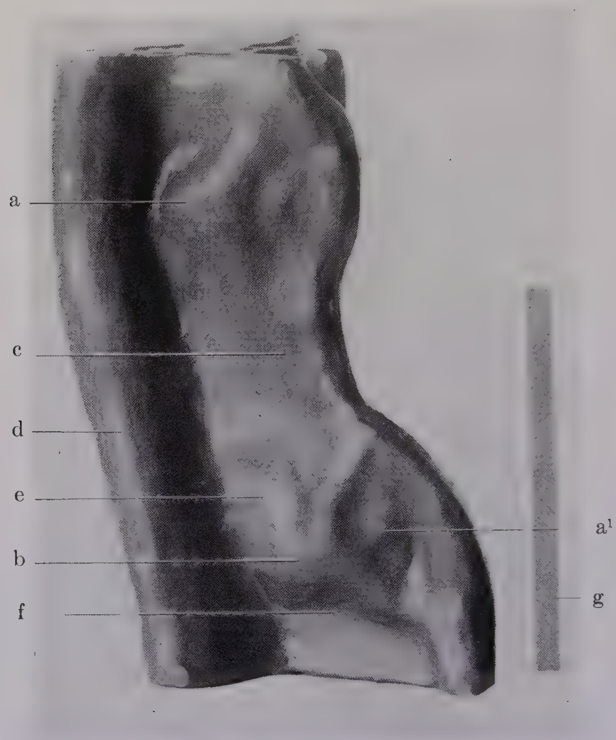


FIG. 171
Model of the toothgerms of the lower central incisor (a) and lateral incisor (a¹) of a 31.4 mm. embryo.
At a and b elevations in the labial side of the toothgerms and dental lamina may be noted which are the lateral enamel strands.
c. dental lamina.
d. lip furrow band.
e. depression medially from the lateral enamel strand.
f. depression distally from the lateral enamel strand.
g. measure 10 cm. long.

the mouth toward the lingual and the labial also may be noted. In this picture the stratum germinativum

of the mouth epithelium may be traced around the dental lamina and toothgerm. Remarkable differences may be noted between the cells of the mouth epithel-

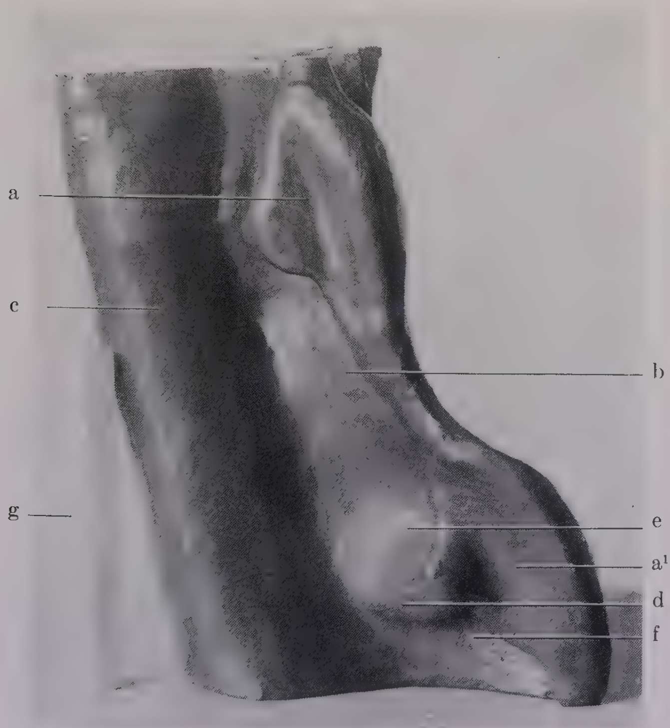


Fig. 172

Model of the toothgerms of the lower central incisor (a) and lateral incisor (a[1]) of a 41.6 mm. human embryo (about 72 days).

b. dental lamina.
c. lip furrow band.
d. lateral enamel strand.
e. medial enamel niche.
f. distal enamel niche.
g. measure 10 cm. long.

ium lying outside the stratum germinativum and the cells in the toothgerm. The epithelium of the mouth shows large cells. In section these large cells appear empty, but stained specifically they are found to be

filled with glycogen. The significance of this fact is not yet clear. It is claimed that the dental lamina and toothgerms are built by the stratum germinativum. We may also observe cell divisions in the early stages

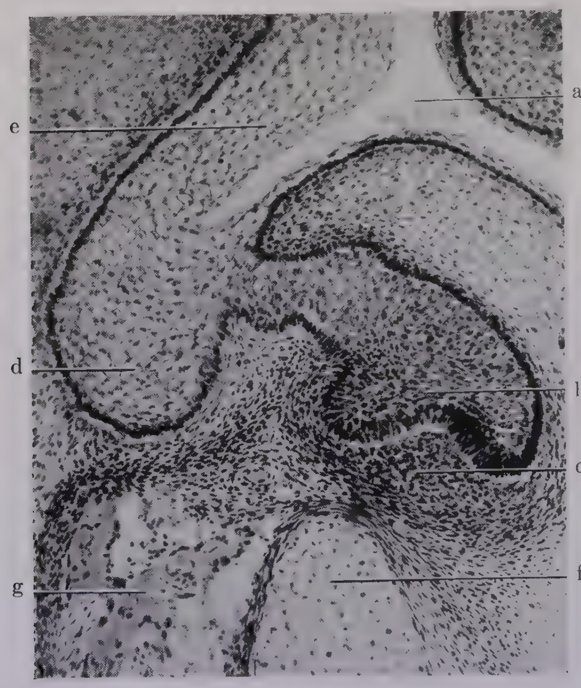


Fig. 173
Section through the central incisor of Fig. 172. Sectioned labio-lingually.
a. mouth cavity. b. toothgerm.
c. condensation of connective tissue around toothgerm.
d. lip furrow band. f. Meckel's cartilage.
e. epithelium toward lip. g. bone.

of development in other layers of epithelium and in the central part of the toothgerms.

In the model Fig. 171 we see that from both toothgerms, processes are extending toward the lip furrow band not quite reaching it. This process is called

Lateral enamel strand

the *lateral enamel strand* (described by *L. Bolk*). It is in this stage of development that this band makes its first appearance. In this model we see a slight groove mesially and distally from the lateral enamel strand which is more pronounced in a model of a 41.6 mm. embryo (72 days). Fig. 172. The lateral enamel strand extends from the labial side of the dental lamina to the labial side of the toothgerm. Above the lateral enamel strand the groove is to be seen limited by the lateral enamel strand, dental lamina, and labial margin of the toothgerm. Below the lateral enamel strand there is also a depression limited by the lateral enamel strand, dental lamina, and distal margin of the toothgerm.

Dental papilla

A section through the middle of the toothgerm shown in Fig. 172 of the central incisor is seen in Fig. 173. In the model Fig. 172 we can already see that the enamel knot is not elevated from the toothgerm as it has been but that a depression appears on the lower end of the toothgerm. *This is the dental papilla from which the dental pulp develops.* At this stage of development the cells forming the outer layer of the toothgerm vary at different places. The cells at the side of the dental papilla corresponding to the enamel knot are longer, and more cylindrical in shape. From these cells later the ganoblasts develop.

Relationship between dental lamina and tooth germs

Considerable discussion has always centered around the mode of development of the toothgerm from the dental lamina. Some believe that the toothgerms develop on the end of the dental lamina, others that they arise from the side of it. Both views have their advocates but both views are based on misconceptions. The toothgerms do not develop on a lamina previously formed, but toothgerm and lamina grow together as shown diagrammatically in Fig. 162. In the beginning there is no lamina (Fig. 163-165), later the toothgerm is found on the end of the lamina (Fig. 166), and after further development the main part of the germ is

located on the labial side of the lamina. (Fig. 170-173). This change of the relationship of the germ and

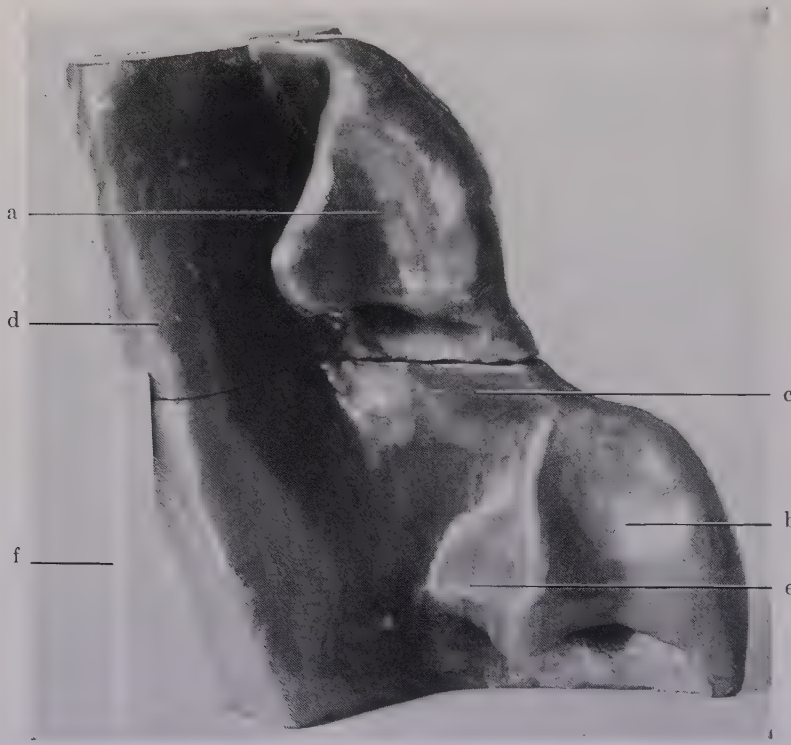


Fig. 174
Model of the toothgerms of a 49.5 mm. human embryo (about 76 days).
a. central incisor.
b. lower lateral incisor.
a and b indicate the dental papillae also.
c. dental lamina.
d. lip furrow band.
e. lateral enamel strand.
f. measure 10 cm. long.

dental lamina is due to an unequal growth of the different parts of the dental anlage.

In Fig. 174 the model of the central and lateral incisors of a 49.5 mm. embryo (76 days) is shown. The toothgerms are seen from the side of the dental

papillae. The depressions of this toothgerm appear deeper than those of the previous stage, due to growth in every direction. In this stage (49.5 mm.) of development the lateral enamel strand is well developed as seen especially in the lateral incisor. *This lateral enamel strand is a second dental lamina which arises from the labial side of the original dental lamina, and extends labially to the toothgerm.* Sometimes this lateral

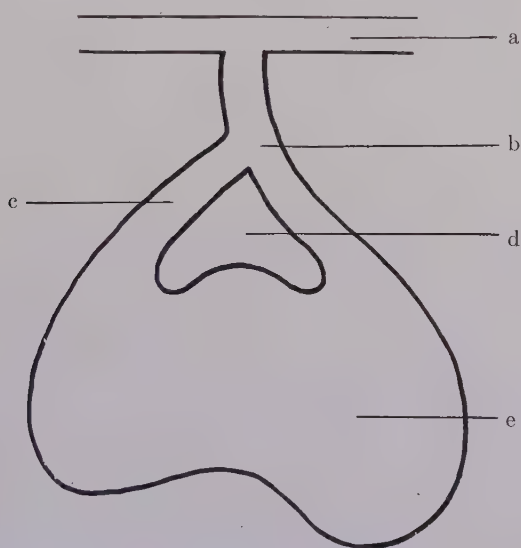


FIG. 175
Diagram showing:
a. Mouth epithelium. c. Lateral enamel strand.
b. Dental lamina. d. Enamel niche.
e. Enamel organ.

enamel strand extends from the toothgerm directly to the mouth epithelium. *The dental lamina runs uninterruptedly from one toothgerm to the other, while the lateral enamel strand is a separate structure in each toothgerm.* The significance of this enamel strand is not understood. *L. Bolk,* who first described this structure, drew the conclusion that the teeth of pri-

mates, and so of humans, are built of two parts—one labial and the other lingual. These two parts have evolved according to *Bolk* from two series of teeth of reptiles. This theory of *Bolk* is the "*Dimer Theory*" which means that every toothgerm of a primate is a dimeric organ, that is to say it is composed

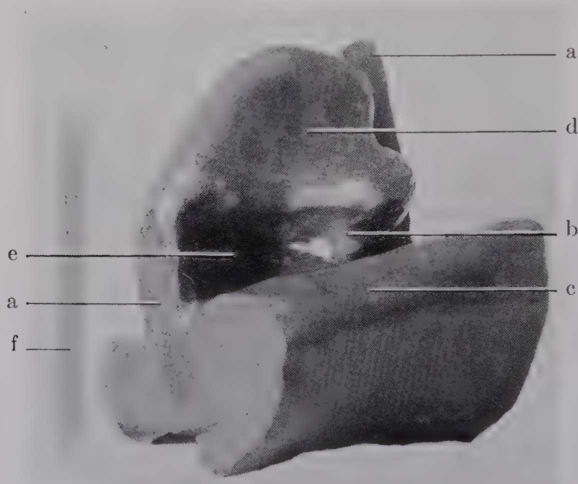


Fig. 176

Model of the central incisor from the case of Fig. 174. Seen from labiomesial side.

Note the medial enamel niche (e).

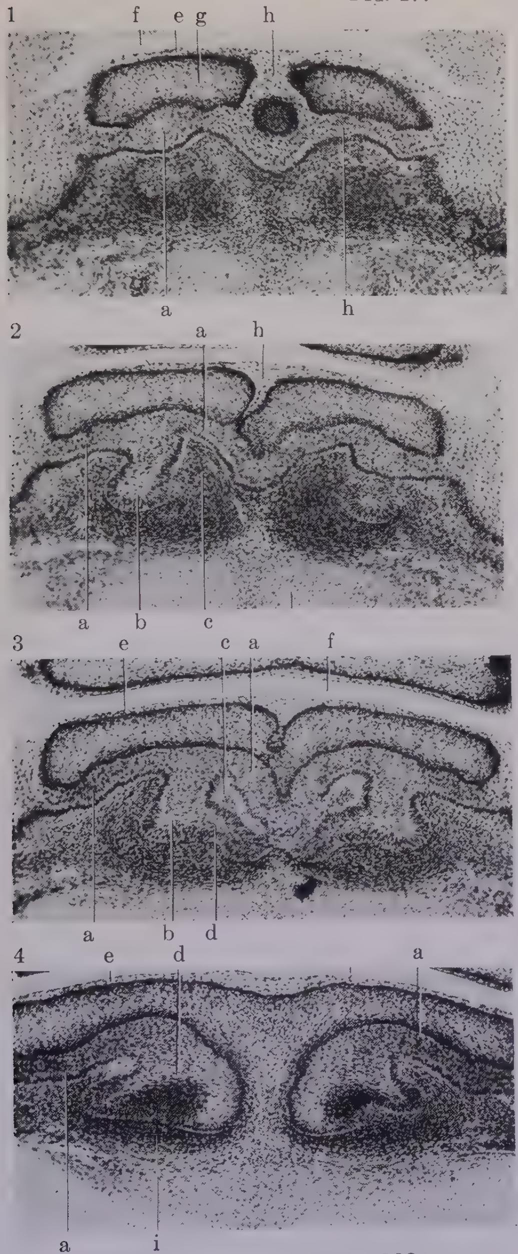
a. dental lamina.
b. lateral enamel strand.
c. lip furrow band.
d. enamel organ.
f. measure 10 cm. long.

of two parts, each one of which has been a complete tooth in the lower orders of evolution.

As *Bolk* described his findings and evolved his theory, he also called attention to other structures of the toothgerms. One of these structures is the "*enamel niche*". The enamel niche is best understood from a diagram. Fig. 175. As previously mentioned there is not one dental lamina, but two; the labial is called

Enamel niche

Fig. 177



Four sections from the series cut in frontal section mesio-distally through the tooth-germs of the lower central incisors of a 49.0 mm. embryo.

The series show the topography of the medial enamel niche.

a. dental lamina.
b. lateral enamel strand.

c. medial enamel niche.
d. enamel organ.
e. mouth epithelium.

f. mouth cavity.
g. connective tissue between a and e.
h. mid line of lower jaw.

Description in text.

the lateral enamel strand, and the lingual, the dental lamina. *These two laminae and the toothgerm form a triangular space which is the "enamel niche."* *Bolk* described the "enamel niche" as being open mesially and closed distally in the incisors, cuspids, and first deciduous molars, but as being open distally and closed mesially in the second molars.

My investigations in this subject have shown that

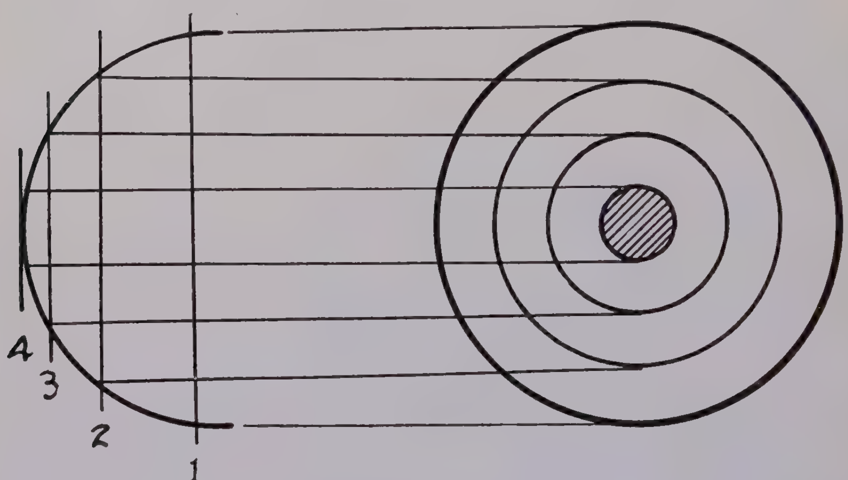


Fig. 178
Diagram showing the serial sections 1, 2, 3, 4 through a half ball.

Bolk's observations are right but also show that they are not complete. *I found, not one niche, but two;* one of these niches corresponds to that described by *Bolk*. This is seen on the model above the lateral enamel strand in Fig. 174. *This medial enamel niche is bounded by the dental lamina, lateral enamel strand, and the labial margin of the toothgerm.* In microscopic serial sections this niche *can be recognized only in frontal sections.* Fig. 176 shows the central incisor of the same model from the mesio-labial side looking from the side of the dental papilla. We see the lip furrow band,

Medial enamel niche

the dental lamina, and the lateral enamel strand. We are looking directly into the medial enamel niche. *This niche is formed by the curved dental lamina, the elevation of the toothgerm, and lateral enamel strand.* If the sections made in a frontal direction are followed serially, a niche opening mesio-labially and closing

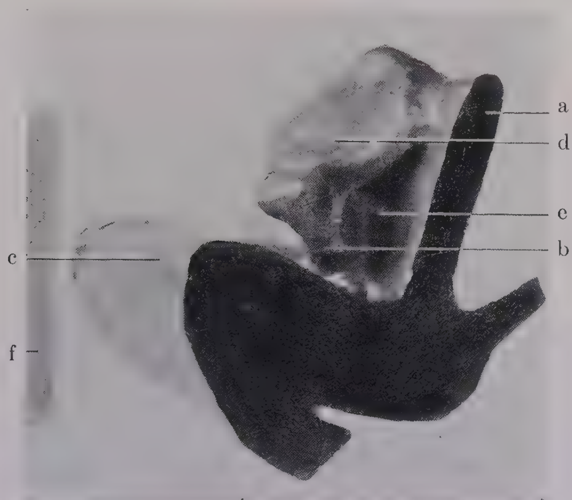


Fig. 179
The same model as is shown in Fig. 176 seen from the distal side. Note the distal enamel niche (e).
a. dental lamina. c. lip furrow band.
b. lateral enamel strand. d. enamel organ.
f. measure 10 mm. long.

distally is observed. In Fig. 177 frontal sections of a 49.0 mm. embryo are shown. This is the same sized embryo as that from which the model was made. The *first* of the four pictures shows the dental laminae of both sides joining at the median line. In the *next* picture the lateral enamel strand appears. In the *third* picture the labial margin of the toothgerm appears and thus the enamel niche is formed. The *fourth* picture is a section more lingual, and the

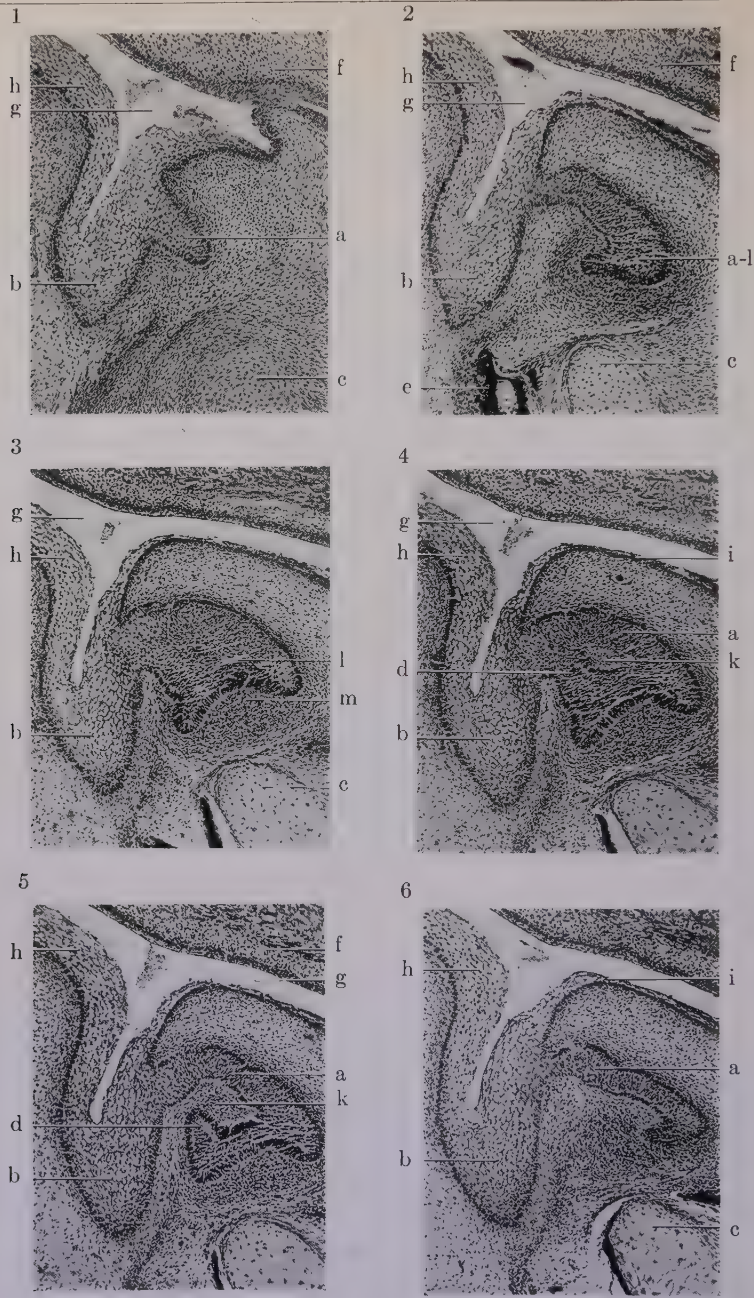


Fig. 180

Six sections cut in sagittal direction labio-lingually through the same specimen from which the model Fig. 174-176 and 179 were made. The sections correspond to the six segments in diagram Fig. 181.

a. dental lamina.
b. lip furrow band.
c. Meckel's cartilage.
d. lateral enamel strand.
e. bone.
f. tongue.
g. mouth cavity.
h. epithelium of lip.
i. epithelium of floor of mouth.
k. distal enamel niche.
l. enamel organ.
m. dental papilla.

enamel niche has disappeared. To understand the topography of the medial enamel niche we may compare it with half of a hollow ball; the curvature is given by the curved dental lamina, and the sides are formed by the elevations of the lateral enamel strand and the labial margin of the toothgerm. When serial sections of this half ball are made parallel to the open side, circles become smaller until finally, the last

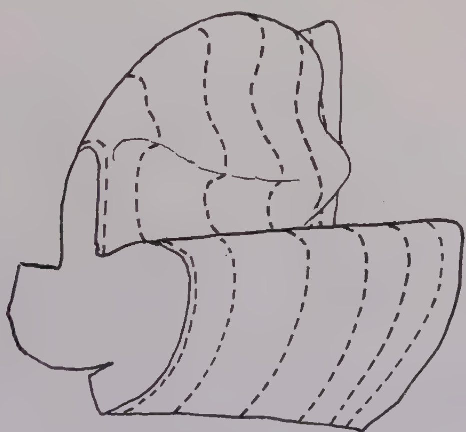


Fig. 181
Diagram of the model Fig. 176 showing the position of the six sections shown in Fig. 180.

section is a closed disc, as shown in Fig. 178. *The same model as shown in Fig. 176 observed from the distal (Fig. 179) shows another niche which is bounded by the dental lamina, lateral enamel strand, and distal margin of the toothgerm.* This distal niche cannot be seen in frontal sections because it is an open space. *This niche can be seen only in sagittal sections.* *Distal enamel niche*

The following illustration Fig. 180 shows sagittal sections of the same toothgerm from which the model Fig. 174, 176, 179 were made. The diagram Fig. 181 shows the positions of these sections of the toothgerm.

Compare the sections with the model Fig. 179. The first picture shows the lip furrow band and the dental lamina near the median line of the jaw. Below the dental lamina is located *Meckel's* cartilage. In the second section the dental lamina is curved (as previously described) and the end of the dental lamina is wider.

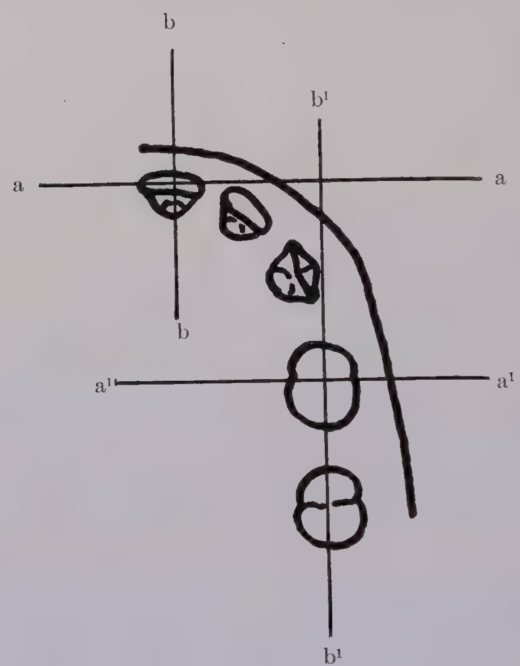


Fig. 182
Diagram showing the direction of the sections.
a.-a frontal: in the front region this is mesio-distal.
a^1.-a^1 labio-lingual in the molar region.
b.-b sagittal: in the front region labio-lingual.
b^1.-b^1 mesio distal in the molar region.

In the third section not only the end of the lamina is wide, but also the whole dental anlage. The fourth picture shows an island of connective tissue in the epithelial tooth anlage. Here we observe for the first time the distal enamel niche. In the fifth section the

lateral enamel strand is separated from the dental lamina. In the sixth picture the dental lamina is extending distally toward the lateral incisor. The comparison with the half ball as made with the medial enamel niche can also be made with the distal niche except that the sections begin with the disc and proceed outward. In order to obtain a clear conception of the relationship between the different parts of the tooth anlage, a thorough study of the pictures, models, and serial sections is absolutely essential.

The distal enamel niche escaped *Bolk's* observation because he studied frontal sections only. The distal niche appears in frontal sections as a bay and not as a niche. The distal enamel niche is to be seen only in sagittal sections. The medial niche appears in sagittal section only as a curve of the dental lamina.

According to my findings, there are two enamel niches on the incisors, one on the distal and one on the mesial, the distal being the deeper. On the cuspids the medial niche appears to be the deeper. In frontal sections, the first deciduous molars have a medial niche as open mesially and closed distally. This applies to both upper and lower jaws. In the upper second molars the niche is more irregular and open distally. The lower second molars are like the first molars. Sagittal sections of molars present a very complicated picture. A sagittal section in the incisor region is a section running labio-lingually, but a sagittal section in the molar region runs mesio-distally. A frontal section in the incisor region is mesio-distal and in the molar region bucco-lingual. (Fig. 182.) It is very difficult to study the relationship between toothgerms and dental lamina in the mesio-distal (sagittal) sections in the molars. Models of this region show that in molars there are not only medial but also distal niches. The relationships however in this region are not so clear as in the front teeth.

During further development the different portions of the toothgerms become more distinct. A model of the lower incisors of a 60.0 mm. human embryo (81 days) is shown in Fig. 183. Marked differences are noted between this picture and the one of the model of the 49.5 mm. embryo. The dental papilla as well as the enamel niches are deeper. The features of the whole anlage are more mature. It is a question whether the deepening of the dental papilla is due to a growth of the connective tissue or whether it is due to the activity of the epithelium. Since there is no indication of an actual epithelial growth into the depths, I believe that the deepening of the dental papilla is not the result of an epithelial downward growth, but of a general development of the entire toothgerm.

Both of the enamel niches become deeper; therefore the toothgerm or the enamel organ is further separated from the dental lamina. In the very early stages of development no differentiation can be made between the dental lamina and the toothgerm. The development of the enamel niches gives rise to the lateral enamel strand. *Through the deepening of the enamel niches the enamel organ becomes more and more separated from its base, the dental lamina.*

In Fig. 184 a toothgerm of the upper first molar of a 54.0 mm. embryo is shown. The dental lamina, lateral enamel strand, and enamel niche (opened mesially) are all well formed. The enamel knot is visible as a condensation of cells in the enamel organ. This specimen shows the formation of stellate reticulum in the enamel organ. As *Bolk* stated, the differentiation of the stellate reticulum does not begin in one place near the middle, of the organ, but in two places as seen in Fig. 184. The central part of the enamel organ retains its original appearance, while the surrounding lateral parts develop the stellate reticulum. This is better illustrated in Fig. 185 which shows the toothgerm of an upper central incisor of a 68.0 mm.

embryo. The central unchanged part in the toothgerm is a cord running from the enamel knot to the outer enamel epithelium. *Bolk* calls this cord "enamel *Enamel cord*

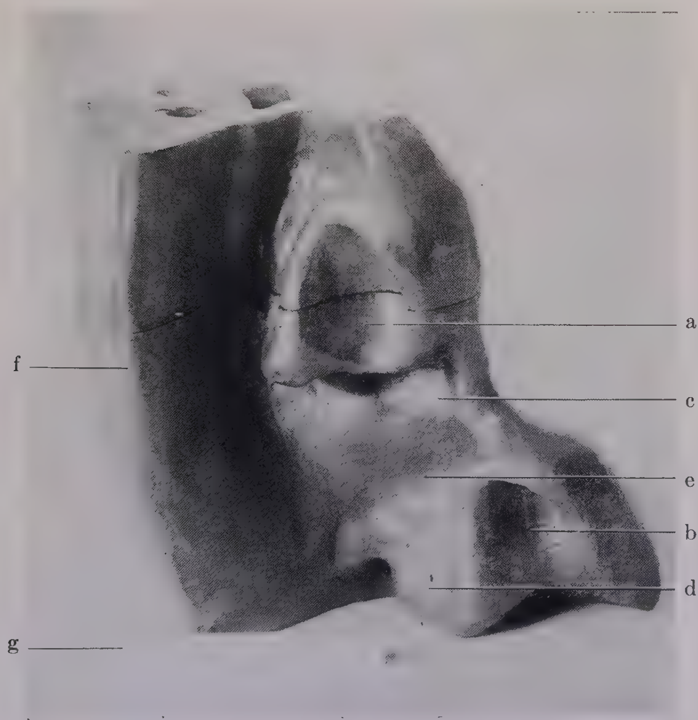


Fig. 183
Model of the toothgerms of a 60.0 mm. human embryo (about 81 days).

a. central lower incisor.
b. lateral incisor.
c. dental lamina.
d. lateral enamel strand.
e. medial enamel niche.
f. lip furrow band.
g. measure 10. cm. long.

septum," *Arhens* "*enamel cord.*" Since it does not divide the organ into two parts, I believe the term "*enamel cord*" is more nearly correct. On both sides of the enamel cord, in reality surrounding it, is seen

the stellate reticulum, described previously in the chapter on the enamel.

Epithelial bud for the permanent teeth

An epithelial bud on the deciduous enamel organ will later develop into the permanent tooth. Whether this bud originates from the outer layer of the enamel organ or from the dental lamina is still an unsettled question. *In all cases coming under my observation the epithelium from the lingual surface of the lamina can be traced without interruption into the bud of the permanent tooth.* Later when the toothgerms separate from the dental lamina, the bud of the permanent tooth does not remain in connection with the deciduous tooth but attached to the end of the lamina.

Enamel navel

Bolk used the presence of the enamel cord as a proof for his "dimer" theory. He claims that it is evidence for the double origin of the primate teeth. Not only the enamel cord but also a contraction frequently found on the top of the enamel organ, the "*enamel navel*," has been used for his interpretation. This enamel navel is illustrated in Fig. 186 taken from the toothgerm of an upper first deciduous molar of an 104.0 mm. embryo, (100 days). The enamel cord and the enamel navel are seen in this picture.

Fig. 187 shows a model of the toothgerms of the central and lateral incisor of an 80.0 mm. embryo (92 days). The germs are viewed distally and show the distal enamel niches. The buds for the permanent teeth are present. In the succeeding stages rapid progress is noted in the development of the toothgerms. In Fig. 188 a model of the central and lateral lower incisors of a 105.0 mm. embryo (100 days) is given. The enamel niches are very deep and undermine the enamel organ from the sides. The lamina for the permanent teeth is farther separated from the lingual side of the toothgerms and is longer. This elongation is not due to a downward growth of the epithelial bud, but is due to a separation upwards

between the dental lamina and the outer layer of the enamel organ.

Fig. 189 shows the model of the toothgerms of the central incisor in Fig. 188 cut in two parts. The upper

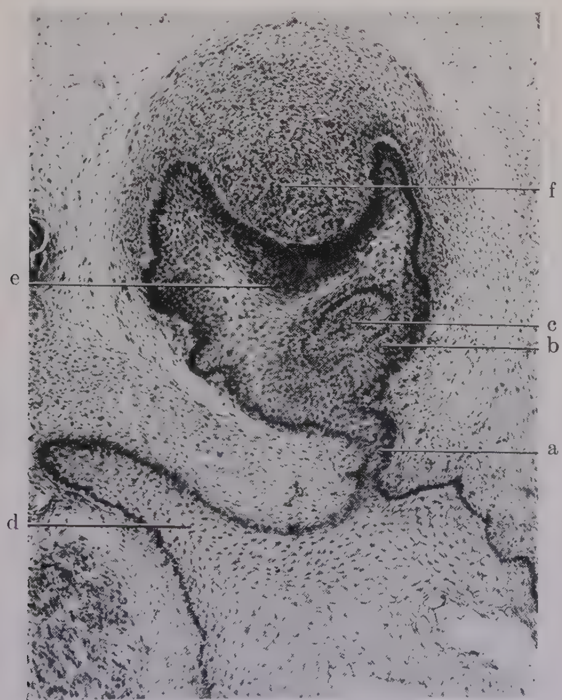


Fig. 184
Toothgerm of an upper first molar of a 54.0 mm. human embryo. Sectioned labio-lingually.

a. dental lamina.
b. lateral enamel strand.
c. enamel niche.
d. lip furrow band.
e. enamel cord.
f. dental papilla.

picture shows the distal portion of the model of the germ; the lower, the plane formed by the cut. *The dental papilla already has the shape of the future enamel covered crown of the tooth.* The upper picture shows the thin connection between the enamel organ and dental

lamina which extends as a bud for the permanent tooth. In the lower picture may be seen the distal enamel niche which has deeply undermined the enamel

Fig. 185
Toothgerm of an upper central incisor of a 68.0 mm. human embryo. Sectioned labio-lingually.
a. dental lamina.
b. lateral enamel strand.
c. enamel niche.
d. lip furrow band.
e. enamel cord.
f. dental papilla.
g. bud for permanent tooth.

organ. The lateral enamel strand is reduced to a small band. Epithelial buds are all that remains from the lateral enamel strand. These are located labially on

the toothgerm on the outer layer of the tooth anlage about at the point where the strand used to be attached. This is shown in Fig. 190 taken from the upper first

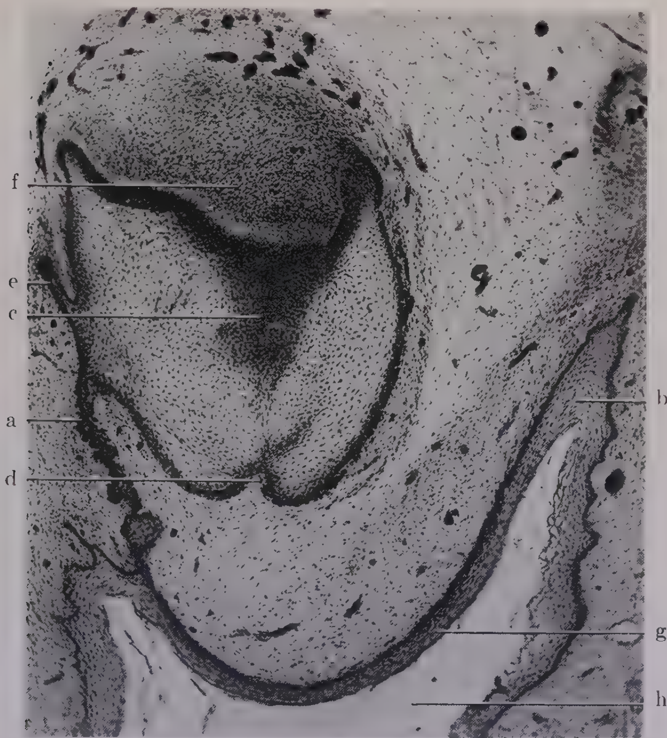


Fig. 186

Tooth of an upper first molar of a 104.0 mm. human embryo. Sectioned labio-lingually.

a. dental lamina.
b. lip furrow band.
c. enamel cord.
d. enamel navel.
e. bud for permanent tooth.
f. dental papilla.
g. mouth epithelium.
h. mouth cavity.

deciduous molar of a 102.0 mm. embryo. Fig. 191 is a microphotograph of the toothgerm from which the model Fig. 189 was made. The section is a mirror image of the lower picture. (Fig. 189). We see the

dental lamina, the remainder of the lateral enamel strand, and the lamina for the permanent tooth. The enamel organ is already differentiated into the regular layers, i.e. outer enamel epithelium, stellate reticulum, stratum intermedium, and ganoblast layer. A slight differentiation of the superficial cells of the dental

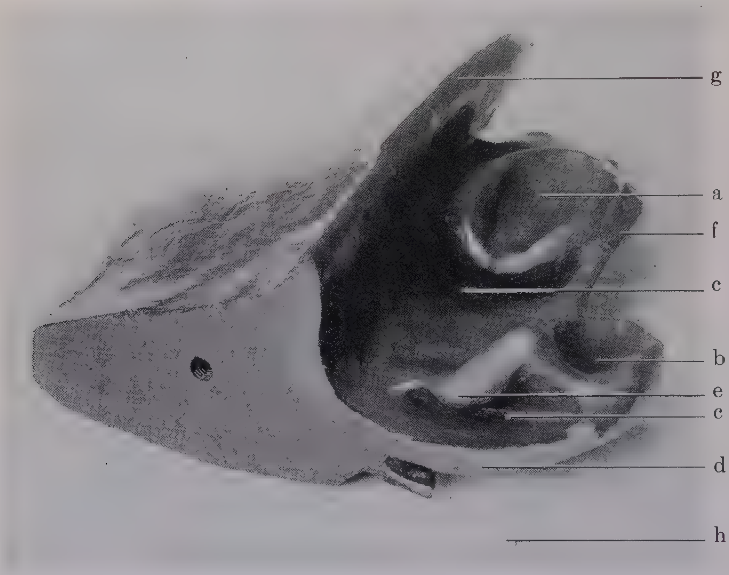


Fig. 187
Model of the toothgerms of a lower central incisor (a) and lateral incisor (b) of an 80. mm. human embryo (about 92 days).

c. distal enamel niche.
d. dental lamina.
e. lateral enamel strand.
f. dental lamina for permanent teeth.
g. lip furrow band.
h. measure 10. cm. long.

papilla can be noted. These differentiated pulp cells will shortly be the odontoblasts. At this stage the toothgerm is almost completely developed; it undergoes changes only in size and cell differentiation. Deposition of dentin and enamel soon follows. In a toothgerm of a 200 mm. embryo (164 days) the

deposition of dentin has begun on the tip of the cusps. (Fig. 192). A thin layer of enamel may also be observed.

The order of development described is so far as we

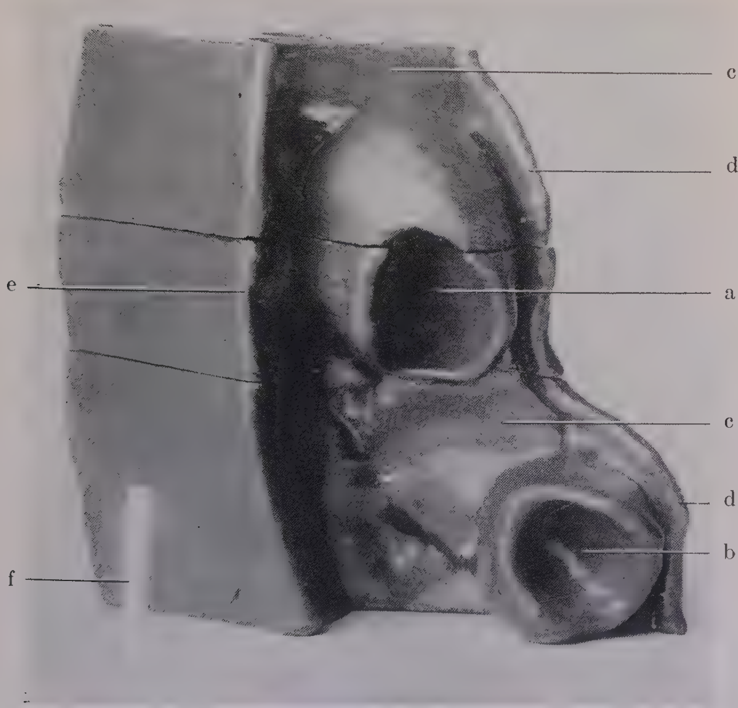


FIG. 188

Model of the toothgerms of a lower central incisor (a) and lateral incisor (b) of a 105.0 mm. human embryo (about 100 days).
c. dental lamina. e. lip furrow band.
d. dental lamina for permanent teeth. f. measure 10.0 cm. long.
a and b also indicate the dental papilla.

know, the same for all the teeth; that is for incisors, bicuspids and molars, uppers as well as lowers.

Changes in the dental lamina

Changes in the dental lamina are taking place. By this time the connection between the dental lamina

and the enamel organ is only a thin epithelial bridge. *The dental lamina is disintegrating. It is no longer a continuous lamina, but is sieve-like.* The buds for

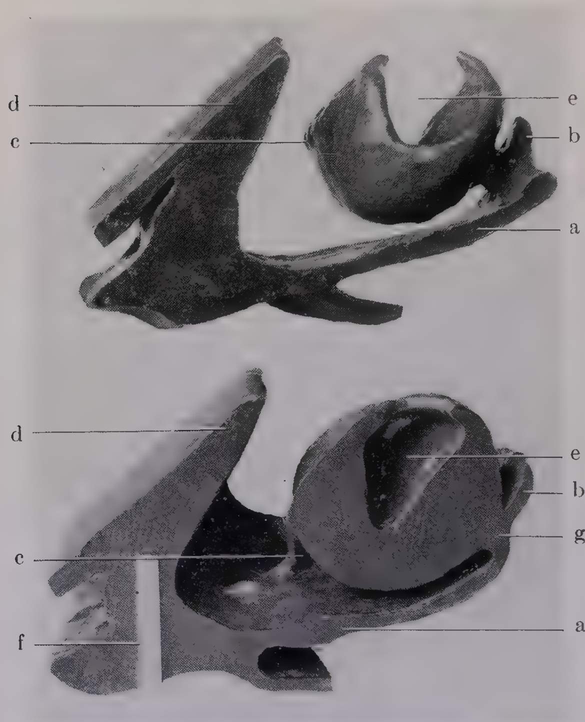


Fig. 189
The central incisor of the case shown in Fig. 188.
a. dental lamina.
b. lamina for permanent teeth.
c. remains of the lateral enamel strand.
d. lip furrow band.
e. dental papilla.
f. measure 10.0 mm. long.
g. connection between lamina and toothgerm.

the permanent teeth are found on the end of the dental lamina. *At some places the disintegrated cells of the dental lamina form concentric-like structures*

with hornified centers. These structures are the so-called epithelial coils or glands of Serres. These structures persist long after tooth eruption, and their function is not known. *Epithelial coils*

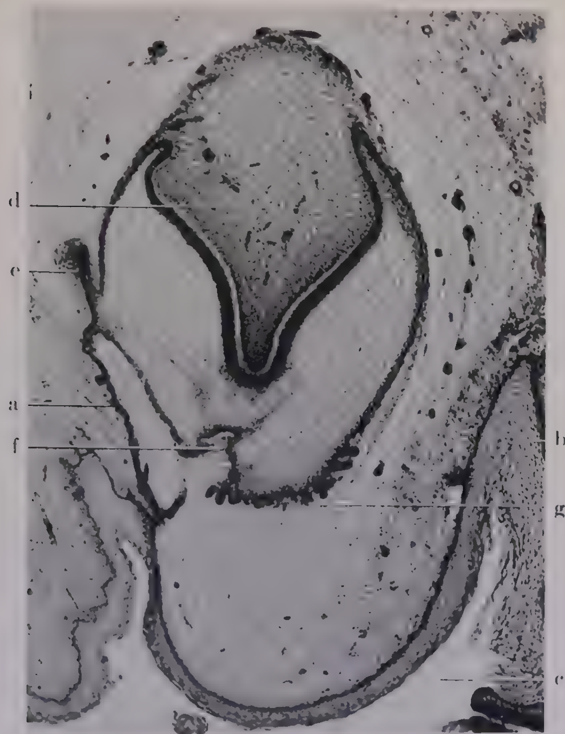


Fig. 190
102. mm. human embryo. Upper first molar. Sectioned labio-lingually.
a. dental lamina.
b. lip furrow band.
c. mouth cavity.
d. dental papilla.
e. bud for permanent tooth.
f. enamel navel.
g. remains of lateral enamel strand.

The development of the dentin and enamel now proceeds in the order described in the chapters on dentin and enamel. The stellate reticulum disappears

in the developmental progress and at about the time of eruption the surface of the enamel is covered with the united enamel epithelium. The tooth now erupts as described in the chapter on tooth eruption. The development of the permanent teeth takes place in the same order as that described for deciduous teeth.

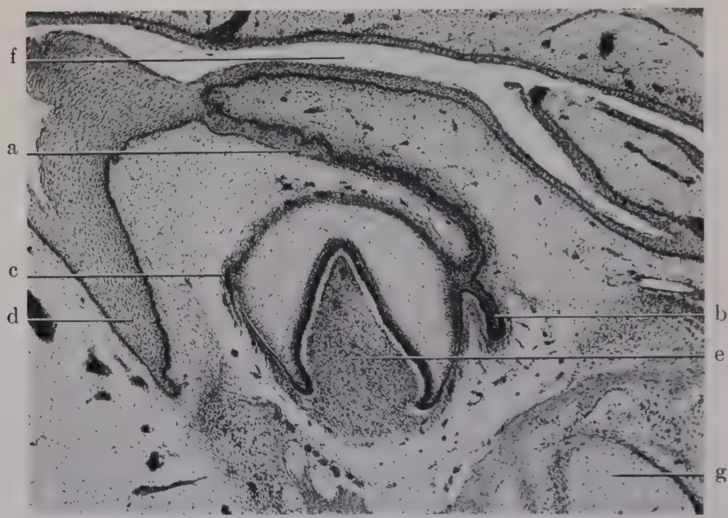


Fig. 191

The section is a mirror image of the plane in the lower picture in Fig. 189. Sectioned labio-lingually.

a. dental lamina.
b. bud for permanent tooth.
c. remain of lateral enamel strand.
d. lip furrow band.
e. dental papilla.
f. mouth cavity.
g. Meckel's cartilage.

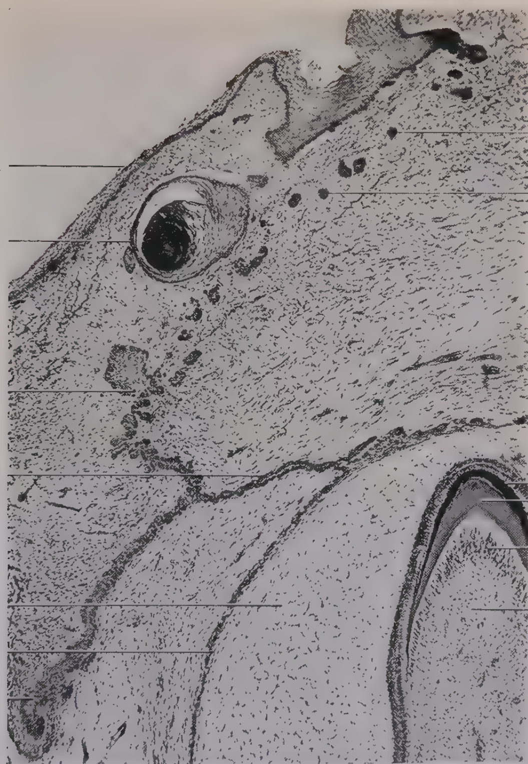


FIG. 192

Central lower incisor of a 200. mm. human embryo (about 164 days). Sectioned labio-lingually.

a. enamel.
b. dentin.
c. odontoblasts.
d. pulp.
e. outer enamel epithelium.
f. stellate reticulum.
g. bud for permanent tooth.
h. connection between toothgerm and dental lamina (i)
k. epithelial remains of dental lamina.
l. epithelial coil.
m. mouth epithelium.

BIBLIOGRAPHY

It is not suitable in a book of this nature to give a complete bibliography of all the papers and books that concern dental histology. I merely call attention to books and papers which carry a large bibliography. Such is the book of I. Howard Mummery. *The Microscopic and General Anatomy of the Teeth.* 1924. Humphrey Milford. Oxford Univ. Press.

In the German literature the book of *H. Eidmann—Die Entwicklungsgeschichte der Zahne des Menschen,* 1923. Berlin, Hermann Meusser, has an almost complete bibliography of the literature from the XVIII century to 1920.

The newer literature is found in the scientific journals. The journals of the United States and Great Britain are too well known to everyone to require mention here. The German journals in which most histologic papers may be found are:

(1) Zeitschrift fur Stomatologie, Urban und Scwarzenberg, Vienna. I. Austria.

(2) Vierteljahrsschrift fur Zahnheilkunde, Hermann Meusser, Berlin. W. 57. Germany.

(3) Deutsche Monatsschrift fur Zahnheilkunde, Julius Springer, Berlin. W. 9. Germany.

(4) Schweizerische Monatsschrift fur Zahnheilkunde, Buchdruckerei Berichthaus, Zurich, Switzerland.

Since 1920, most of the publications of *B. Gottlieb* have appeared in the *Zeitschrift fur Stomatologie,* which publishes the summaries of important papers and the descriptions of the illustrations in English—at the suggestion of the Scientific Commission of the F. D. I. This journal, as well as the other three, has published all the papers of the pupils of *Gottlieb: R. Kronfeld, J. Weinmann, E. Kotanyi, L. Bencze,*

G. Stein, A. Klein, A. M. Schwarz, R. Grohs, J. Fridrichovsky, J. Kohler, E. Kellner, M. Leist, B. Orban. Most of the papers of other investigators who write in German have appeared in these journals: *O. Walkhoff, P. Adloff, G. Fischer, H. Euler, O. Weski, W. Adrion, W. Meyer, R. Weber, E. Smreker, L. Fleischmann, H. Sicher, A. Oppenheim*, etc. Most of the papers of these investigators cover the entire literature of the subjects they discuss.

Special attention must be called also to the book edited by *Julius Misch*—"*Die Fortschritte der Zahnheilkunde*," Berlin, published by Georg Thieme, Leipzig, in which each year the same authors discuss the same subjects with special reference to recent publications pertinent to their subjects. The complete bibliography that appears in each issue of this publication gives this book a particular value.

All references in this book may be found in the fore-going literature.

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